FIRE MANAGEMENT

COST-EFFECTIVE WILDERNESS FIRE MANAGEMENT: A CASE STUDY IN SOUTHERN CALIFORNIA

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Abstract—Federal wilderness fire management policies have been scrutinizedsince the catastrophic fires in the Greater Yellowstone Area in 1988. While wilderness fire management objectives are still aimed at recreating natural fire regimes, all USDA Forest Service fire management programs must be cost-effective. Since current Forest Service economic analyses do not fully represent the value of fire to wilderness, a cost-effectiveness analysis was developed to compare wilderness fire management options. The analytical procedure is briefly reviewed, illustrated through a southern California case study and case study results are discussed. These results suggest that containment of some fires may be more cost-effective than current control-oriented practices.

Federal wilderness fire management policies have been scrutinized since the catastrophic fires in the Greater Yellowstone Area in 1988. Catastrophic,in this context, is a fire of any size that results in excessive resource damage, excessive suppression costs, excessive damage to private inholdings, or loss of life (Saveland 1986). No lives were lost in Yellowstone and many have argued the benefits, rather than damages, of these fires to the Yellowstone ecosystems, but private lands were damaged and suppression costs were excessive (US Senate 1988). While wilderness fire management objectives are still aimed at recreating natural fire regimes, all Forest Service fire management programs must be cost-effective. If these objectives were difficult to implement in Yellowstone, they will be even more so in southern California, where chaparral covered wilderness areas are often surrounded by high valued private property and improvements. The Forest Service's range of options to meet these objectives include the use of appropriate suppression responses and prescribed fire.

Prescribed fires can take two forms: prescribed natural fires and management ignited prescribed fires (USDA Forest Service 1989). All prescribed fires are monitored and managed through the use of detailed burn plans (USDA Forest Service 1989). Theoretically, the only difference between the two forms of prescribed fire is the source of the ignition, but the timing of the fires is also often different. Prescribed natural fires are naturally occurring unplanned ignitions usually caused by infrequent summer or fall lightning storms. Management ignited prescribed fires are ignited by Forest Service personnel on their own time schedule when burning conditions and resource availabilities are optimal (usually late fall, winter, or spring in southern California).

Any fire not classified as a prescribed fire is a wildfire and must receive an appropriate suppression response. These responses range from intensive suppression efforts aimed at keeping the fire as small as possible (a control response) to containment or confinement responses. Containment means surrounding a fire with minimal control lines and utilizing natural barriers to stop its spread. Confinement means limiting a fire's spread to a predetermined area principally using natural barriers, preconstructed barriers, or environmental conditions (USDA Forest Service 1989).

A cost-effectiveness analysis has been developed to compare these options for wilderness fire management programs (Childers and Piirto 1989). In this analysis, approximating the average annual burned area of the natural fire regime is defined as the objective, fire gaming is used to develop representative fire costs and sizes, and decision trees are used to develop expected annual cost and burned area values for a range of fire management alternatives. This paper briefly reviews the analytical procedure, illustrates the procedure through a southern California case study (two contiguous wilderness areas on Los Padres National Forest, Santa Barbara, CA.), and discusses the case study results.

THE STUDY AREA

Our case study area comprises 231,500 acres of the Dick Smith and San Rafael Wilderness Areas on Los Padres National Forest (fig. 1). The vegetation of this area is predominantly chaparral brush species, including chamise (Adenostoma fasciculatum), assorted ceanothus and manzanita species (Ceanothus spp. and Arctostaphylos spp.), two types of scrub oak (Quercus dumosa and Q. turbinella) and several other pyrophytic shrubs. The chaparral intergrades with coast live oak (Quercus agrifolia) in some riparian areas, big cone Douglas fir (Psuedotsuga macrocarpa) and digger pine (Pinus sabiniana) on some north slopes, and a variety of other pines at higher elevations. Fire is a natural component of all of these ecosystems.

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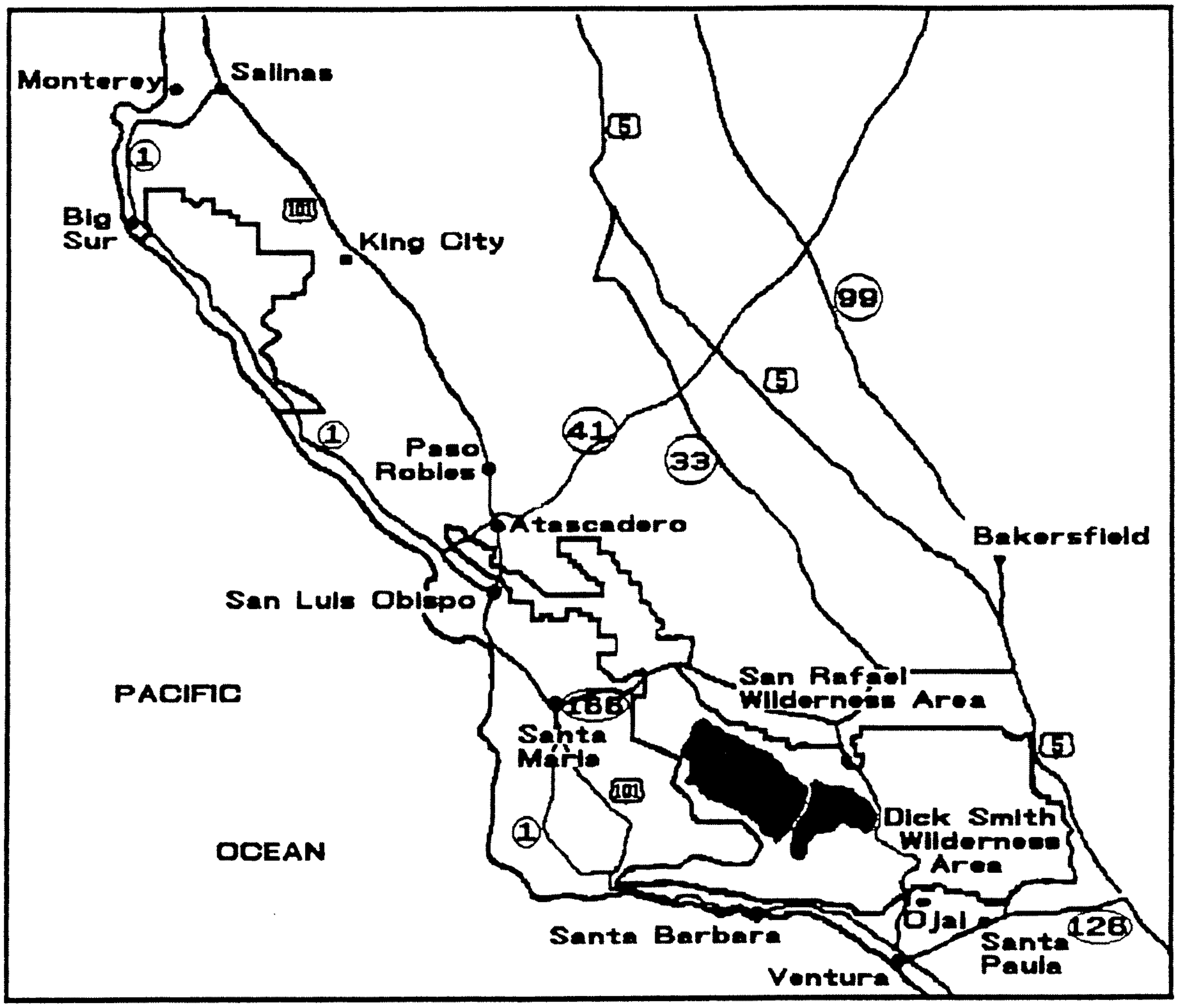

Figure 1--Los Padres National Forest, with the Dick Smith and San Rafael Wilderness Areas highlighted

COST-EFFECTIVENESS ANALYSIS

Most Forest Service economic analyses use cost-benefit models. For example, economic analysis of forest level fire management programs is based on the Cost Plus Net Value Change (C + NVC) model (USDA Forest Service 1987). C + NVC computes the sum of program costs and the quantifiable (in monetary terms) effects of fire on resource values. To be efficient, these cost-benefit analyses must include the effects of fire on all relevant resources. C + NVC models currently include fire effect values for many primary forest resources such as timber, minerals, and forage, and many wilderness outputs such as water, fish and wildlife (measured in numbers of visits by hunters and fishermen), and recreational use (USDA Forest Service 1987). Fire's effects on these resources can be and usually is much different than its effects on a wilderness ecosystem. Since the primary economic value of wilderness remains undefined, fire's effects on wilderness also remain undefined. A cost-benefit analysis which does not include all of the relevant costs and benefits will be incomplete, and often misleading (Williams 1973). Therefore, analyses based solely on C + NVC models are inadequate for wilderness fire management planning.

Saveland (1986) avoided this C + NVC problem in a cost-effectiveness comparison of fire management options for the Frank Church-River of No Return Wilderness Area. In his Analysis, the costs of each alternative were the expected annual suppression costs. "Effectiveness" was the approximation of the average "natural" annual burned area based on what fire history studies revealed. Saveland (1986) justified this well: Plant communities require a certain amount of fire, just as they require a certain amount of precipitation...Altering the average annual burned area would be like altering the average annual rainfall. Though Saveland's analysis involved a different fire regime and setting, his definitions and much of his methodology are appropriate for southern California's chaparral.

Cost-effectiveness analysis (CEA), in its truest form, compares the costs of different alternatives, where each alternative will meet the desired objectives, or have the same effects. A CEA has five key elements: the objective; the alternatives; the costs; the model; and a criterion for ranking the alternatives (Quade 1967).

The Objective

The most important, and often the most difficult, step in CEA is a clear definition of the goals or the objectives. Public policy usually includes several goals or objectives and these are often conflicting (Quade 1982). Forest Service Policy is no exception. The Forest Service Manual (USDA Forest Service 1986) defines two objectives for wilderness fire management:

1. (to) permit lightning caused fires to play, as nearly as possible, their natural ecological role in wilderness;

2. (to) reduce to an acceptable level, the risks and consequences of wildfire within wilderness or escaping from wilderness.

The value of fire playing its natural ecological role is currently unquantifiable in monetary terms; thus, it is not included in Forest Service economic evaluations. The consequences of fire are more straight forward. They include resource and property damage and suppression costs. Risk, while also difficult to quantify monetarily, is the probability of a fire resulting in excessive resource damages or suppression costs. Current Los Padres National Forest fire management plans stress the second objective (reducing the risks and consequences); proposed wildfire responses are suppression intensive (control and contain strategies) and no wilderness prescribed fires have been planned. The Forest's current wilderness fire management objective might be to respond to and suppress each ignition at minimal cost, regardless of annual burned area. If we are interested in allowing lightning fire to play its natural role, this must be included in the analysis. Our redefined objective might then be to recreate the natural fire regime at minimal cost.

To further define this objective, we need to look at the natural fire return interval. By defining the maximum time interval between fires, we can determine the minimal average annual burned area required to recreate the natural fire regime. Research suggests that the area's chaparral historically burned every 30 years (Byrne 1979, Minnich 1983). Los Padres National Forest fire records (1911-1987) suggest that the chaparral burns every 45 years (USDA Forest Service 1988). Forty-five years probably represents the maximum fire return interval since these records were taken while all fires were being actively suppressed. Using the 45-year return interval, an average of over 5,000 acres of the 231,500-acre study area would have to burn annually. It is important to note that this 5000-acre average is a long-term objective, not an annual goal. In some years, 20,000-30,000 acres might burn while in other years no prescribed fires will be implemented (just as lightning strikes frequently in some years, while no lightning activity occurs in other years).

The Alternatives

Four alternatives were chosen for the Los Padres CEA.

1. Alternative 1 is the Forest Service's past policy: Control all wildfires regardless of cause, and attempt to meet annual burned area objectives through prescribed burning.

2. Alternative 2 is the fire management strategy proposed in the Los Padres' Land Management Plan: Contain all fires which occur under low intensity and control all moderate to high intensity fires, while pursuing an active prescribed burning program.

3. Alternative 3 (the Confinement Alternative): Confine all low intensity starts, contain moderate to high intensity starts, and control only the starts which occur under extreme fire weather conditions (augmented by prescribed burning as needed).

4. Alternative 4 (the Prescribed Natural Fire Alternative): The same as Alternative 3, with the addition of an approved plan for prescribed natural fire management.

The Costs

Only the relevant variable costs should be included in a CEA (Quade 1982).

Fixed costs--those that remain the same for each alternative--should not be included. For this analysis, fixed costs include fire suppression equipment, suppression manning levels, and fire management personnel, because these forestwide resource level requirements are based on over 100 fires a year and an average of less than two ignitions occur annually in the case study area. The variable costs that must be considered are annual suppression costs, prescribed fire costs, and NVCs for fires originating in the study area.

The Model

A model is a simplified representation of the real world which includes all of the relevant features (Quade 1967). Decision trees can be used to evaluate alternative fire management programs in the face of uncertainties about future fire occurrences, weather, behavior, and sizes (Hirsch and others 1981). Decision trees are used to develop expected values. Expected values are probability weighted averages of all possible outcomes. Expected values are not predictions of actual future costs due to the many variables involved in wildland fires; they provide relative values for comparison. For our analysis, decision tree probabilities were derived from fire history records. The range of cost and burned area values were developed through fire gaming since no historic or comparable fire history records were available for containment, confinement, or prescribed natural fire responses (Childers and Piirto 1989).

Alternative	Representative Location	Cause	Weather Pattern	Strategy	Gamed Cost	Expected Value Cost	Gamed Size	Expected Value Size	Gamed Fire NVCs	Expected Value NVCs
Alternative 4	R.L. 1 0.296	Lightning 0.385	A(.441)	CF(.75)	$3,095	$117	4.0	0.2	$44	$2
				Rx(.25)	$3,689	$46	4.0	0.1	$44	$1
			B(.118)	CF(.75)	$6,530	$66	450.0	4.5	$1,976	$20
				Rx(.25)	$6,941	$23	450.0	1.5	$1,976	$7
			C(.147)	CA	$51,730	$867	265.0	4.4	$5,569	$93
			D(.294)	CA	$41,403	$1,387	390.0	13.1	$6,825	$229
		Person 0.615	A(.100)	CF	$3,095	$56	4.0	0.1	$44	$1
			B(.200)	CF	$6,530	$238	450.0	16.4	$1,976	$72
			C(.200)	CA	$51,730	$1,883	265.0	9.6	$5,569	$203
			D(.500)	CA	$41,403	$3,769	390.0	35.5	$6,825	$621
	R.L. 2 0.25	Lightning 0.933	A(.441)	CF(.75)	$2,887	$223	3.0	0.2	($138)	($11)
				Rx(.25)	$47,814	$1,230	740.0	19.0	($20,736)	($533)
			B(.118)	CF(.75)	$163,384	$3,373	1,950.0	40.3	($24,608)	($508)
				Rx(.25)	$182,254	$1,254	1,965.0	13.5	($25,236)	($174)
			C(.147)	CA	$93,335	$3,200	780.0	26.7	($19,585)	($672)
			D(.294)	CA	$527,336	$4,416	4,200.0	35.2	$240,938	$16,522
		Person 0.067	A(.100)	CF	$2,887	$5	3.0	0.0	($138)	$0
			B(.200)	CF	$163,384	$547	1,950.0	6.5	($24,608)	($82)
			C(.200)	CA	$93,335	$313	780.0	2.6	($19,585)	($66)
			D(.500)	CA	$527,336	$36,162	4,200.0	288.0	$240,938	$2,018
	R.L. 3 0.364	Lightning 0.938	A(.441)	CF(.75)	$2,525	$285	0.1	0.0	($3)	$0
				Rx(.25)	$4,821	$181	0.1	0.0	($3)	$0
			B(.118)	CF(.75)	$401	$12	0.1	0.0	($3)	$0
				Rx(.25)	$110,546	$1,113	833.0	8.4	($16,435)	($166)
			C(.147)	CF(.75)	$17,807	$670	40.0	1.5	($1,315)	($50)
				Rx(.25)	$88,639	$1,112	835.0	10.5	($20,544)	($258)
			D(.294)	CA	$910,362	$91,383	2,600.0	261.0	$4,847	$487
		Person 0.062	A(.100)	CF	$2,525	$6	0.1	0.0	($3)	$0
			B(.200)	CF	$401	$2	0.1	0.0	($3)	$0
			C(.200)	CA	$17,807	$80	40.0	0.2	($1,315)	($6)
			D(.500)	CA	$910,362	$10,273	2,600.0	29.3	$4,847	$55
	R.L. 4 0.091	Lightning 1.000	A(.441)	CF(.75)	$3,475	$105	5.0	0.2	($116)	($3)
				Rx(.25)	$48,227	$484	740.0	7.4	($20,734)	($208)
			B(.118)	CF(.75)	$167,088	$1,346	1,955.0	15.7	($24,553)	($198)
				Rx(.25)	$183,371	$492	1,970.0	5.3	($25,181)	($68)
			C(.147)	CA	$98,496	$1,318	800.0	10.7	($18,904)	($253)
			D(.294)	CA	$973,519	$26,046	2,800.0	74.9	$60,638	$1,622
				Expected Values:		$194,083		942.5		$18,697
				Expected Annual Values:		$341,586		1,658.8		$32,907

Figure 2--The decision tree for Alternative 4

A decision tree must be completed for each alternative, using the same probabilities but with different suppression responses and thus different cost and burned area values. The probabilities for each branch of the trees were calculated from the 25-year (1963-87) fire history of the San Rafael and Dick Smith Wilderness Areas (Childers and Piirto 1989). The decision tree for Alternative 4 of the Los Padres study (fig. 2) illustrates the values and probabilities which were developed for our CEA. Alternative 4's decision tree is presented since it is the most complex decision tree (this is the only alternative in which strategy is not solely based on weather pattern).

Fire gaming is the prediction of representative fire sizes by fire management professionals. Predictions are based on the interactions of estimated fire behavior conditions and given suppression force responses (Harrod and Smith 1983). Our gamers included the fire management personnel from the Forest Supervisor's Office and from each of the three ranger districts responsible for the case study area. The "games" consisted of first mapping an overlay of the free-burning fire spread (without any suppression efforts) for a series of time periods. Four weather patterns were mapped at each location and these "fires" were then controlled, contained, confined and managed as prescribed natural fires to develop the cost and burned area values needed to fill in each decision tree. Net Resource Value Changes (NVCs) were calculated using the Forest's 1988 NVC values based on acreage burned by intensity level in each watershed (Childers 1991).

Management ignited prescribed fire costs were subjectively estimated at $50 per acre by the gamers and by the Santa Barbara Ranger District's Fuels Management Staff. This is more expensive than most recent prescribed fires adjacent to the case study wilderness areas, but initial wilderness prescribed fires will probably be expensive due to the age and continuity of the fuelbeds, remoteness of the fires, and limitations on control lines and the use of mechanized equipment in wilderness.

A Criterion

The criterion for ranking alternatives depends on the agency's goals and objectives. Many different rankings are possible. For this analysis, we defined our objective as the recreation of the natural fire regime at minimal cost. Given current budgetary constraints, minimizing costs regardless of burned area might be the agency's actual objective. The sources of proposed expenditures (i.e., forest fire fighting funds vs. program or budgeted dollars) might be important considerations. Risk is also a concern. Finally, the ignition source and timing of the fires might be important to prescribed fire planners. Therefore, all of this information must be provided.

RESULTS

Four weather patterns were gamed at each of four fire locations: the first set at representative fire location (RL) 1, the second at RL 2, the third at RL 3, and the fourth set under double ignition conditions (two fires occurring simultaneously) using RLs 2 and 4 (Childers 1991). The results of these games are presented in table 1. These values

Table 1--Final size and cost figures for gamed fires.

	CONTROL		CONTAIN		CONFINE		Rx Natural Fire	
	Size (acres)	Cost ($)	Size (acres)	Cost ($)	Size (acres)	Cost ($)	Size (acres)	Cost ($)
Representative Fire Game 1								
Weather Pattern A	0.5	7,693	0.5	5,113	4.0	3,095	4.0	3,689
Weather Pattern B	2.0	7,900	2.0	4,722	450.0	6,530	450.0	6,941
Weather Pattern C	120.0	84,592	265.0	51,730	(not gamed)		(not gamed)	
Weather Pattern D	40.0	36,989	390.0	41,403	(not gamed)		(not gamed)	
Representative Fire Game 2								
Weather Pattern A	0.3	3,129	0.3	2,756	3.0	2,887	740.0	47,814
Weather Pattern B	70.0	40,498	780.0	47,792	1,950.0	163,384	1,965.0	182,254
Weather Pattern C	145.0	86,604	780.0	93,335	(not gamed)		(not gamed)	
Weather Pattern D	1,090.0	366,894	4,200.0	527,336	(not gamed)		(not gamed)	
Representative Fire Game 3								
Weather Pattern A	0.1	8,415	0.1	4,427	0.1	2,525	0.1	4,821
Weather Pattern B	0.1	7,541	0.1	4,896	0.1	401	833.0	110,546
Weather Pattern C	5.0	18,249	10.0	9,029	40.0	17,807	835.0	88,639
Weather Pattern D	500.0	370,193	2,600.0	910,362	(not gamed)		(not gamed)	
Representative Fire Game 4								
Weather Pattern A	0.5	3,275	0.5	2,903	5.0	3,475	740.0	48,227
Weather Pattern B	75.0	44,518	785.0	61,549	1,955.0	167,088	1,970.0	183,371
Weather Pattern C	310.0	136,861	800.0	98,496	(not gamed)		(not gamed)	
Weather Pattern D	2,260.0	851,674	2,800.0	973,519	(not gamed)		(not gamed)	

were then run through the appropriate alternatives' decision trees (as per Childers and Piirto 1989) and expected values for average annual suppression costs, burned area, and NVCs were calculated for each decision tree. These results are presented in table 2.

Table 3 includes a breakdown of annual suppression costs and acreage into prescribed fire and forest fire fighting (FFF) costs. Table 3 also illustrates the prescribed burn acreage and costs that would be required to meet our 5,000-acre average annual burned area objective under each alternative. All cost values are presented in 1988 dollars.

DISCUSSION

One of the most obvious observations from the decision tree results (table 2) and the total cost of implementing each alternative (table 3) is that alternatives 1 and 2 are very similar, as are alternatives 3 and 4. This can be attributed to the similarity of the containment and control responses and the confinement and prescribed natural fire responses as they were used on many of the gamed fires. One gamer concluded that they were still "fighting" the fires, even under the prescribed natural fire responses. For example, the actual dispatch cards of initial attack resources were used to determine who would respond to each fire under both containment and control; thus, many of the same resources were used on both of these strategies. The run cards were heavily modified for confinement and prescribed natural fire responses, but the objectives of these two were often similar. Once these strategies have been implemented, familiarity with appropriate suppression responses and pre-approved prescribed fire burn plans should lead to greater differences in their results. Despite the similarities, these results do provide some valuable information for the decisionmaker.

Table 2--Average annual wildfire and prescribed natural fire cost, cost and San Rafael Wilderness Areas highlighted per acre managed, average annual burned area, and average annual cost per area burned for four alternative fire management programs for the Dick Figure 2--The decision tree for Alternative 4 Smith and San Rafael Wilderness Areas

	Average annual cost	Cost per acre managed	Average annual burned area (acres)	Average annual cost per burned acre
Historical			5000+	
Alternative 1	$197,611	$0.85	394.8	$500.53
Alternative 2	$195,474	$0.84	447.2	$437.11
Alternative 3	$334,773	$1.45	1,580.0	$211.88
Alternative 4	$341,586	$1.48	1,658.8	$205.92

Table 3--Breakdown of total average annual suppression/management costs and burned areas by source

	ALTERNATIVE 1	2	3	4
Wildfire Acreage:	394.8	447.2	1,580.0	1,543.2
Rx Natural Fire Acreage:	0.0	0.0	0.0	115.6
Mgt Ign Rx Fire Acreage:	4,605.2	4,552.8	3,420.0	3,341.2
F.F.F. Costs:	$197,611	$195,474	$334,773	$331,140
Rx Natural Fire Costs:	0	0	0	$10,446
Mgt Ign Rx Fire Costs:	$230,260	$227,640	$171,000	$167,060
Total Annual Costs:	$427,871	$423,114	$505,773	$508,646

If the agency's goal was simply to respond to and suppress or manage each ignition at minimal cost, regardless of annual burned area, alternative 2 would be the most cost-effective. This result is due to the cost-saving advantages of containment over control on most lower intensity fires and the expensive outcomes that can result from trying to confine or manage fires in the decadent fuelbeds.

If, however, the goal is to recreate the natural fire regime (i.e., to meet the 5,000-acre average annual burned area), the decision might be a little more involved. Alternative 2 would still be the least expensive, but alternatives 3 and 4 would require much less program or budgeted dollars to accomplish the objective and result in much more of the acreage burning under natural conditions (natural ignition sources and during the natural fire season).

Containment or confinement strategies can only be used when they are less expensive than controlling a given fire (USDA Forest Service 1989). Table 1 shows that containment cost less than control 56 percent of the times it was used and that confinement cost less or about the same as control 78 percent of the times it was used. This suggests that containment and confinement are both feasible and cost-effective for our case study area.

Risk is incorporated into the analysis through the probability of a fire resulting in excessive resource damages or suppression costs (e.g., fire 4D, which cost over $850,000 to suppress regardless of the strategy used). However, none of the confinement or prescribed natural fire responses resulted in a catastrophic fire, and it could be argued that $953,000 (the most expensive gamed fire) is not really catastrophic when compared to historic fires like the 1966 Wellman Fire. The Wellman Fire burned 93,600 acres of the case study area and cost over $6.2 million (in 1988 dollars) to suppress. But, since the Wellman Fire occurred under extreme site-specific weather conditions, it would receive a control response under any alternative; and, since it became catastrophic despite control efforts (the only possible response in 1966) it could happen again under any alternative. The risk of another catastrophic fire might seem greater under alternatives 3 and 4, since fires are allowed to get larger, but this is only the short term risk factor. These alternatives would allow more acres to burn under natural conditions, resulting in cleaner burns than management ignited off-season fires and larger breaks in the decadent fuelbeds, which should help to limit the size of future fires.

SUMMARY

Developing cost-effective wilderness fire management programs is a dilemma faced by many Forest Service land managers. Wilderness fire management is a requirement, but the value of fire in wilderness remains undefinable in monetary terms so it is excluded from most Forest Service economic analyses. Therefore, cost-effectiveness analysis, using the recreation of the natural fire regime as the objective, can provide important economic information. Decision trees help us predict future fire occurrence potentials, and intensive gaming efforts help us estimate fire sizes and costs associated with the implementation of appropriate suppression responses and prescribed natural fires. Case study results suggest that appropriate suppression responses could provide cost-effective alternatives to current control-oriented practices. Through this extensive and thorough cost-effectiveness analysis we can, hopefully, avoid some of the costly mistakes of past experiences in wilderness fire management.

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ADAPTIVE FIRE POLICY

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Abstract—Adaptive resource management is a continuous learning process in which current knowledge always leads to further experimentation and discovery. Adaptive management evolves by learning from mistakes. Designing adaptive management strategies involves four tasks. First, the problem must be defined and bounded. There is growing recognition of the need to define and bound problems at the landscape level. Second, existing knowledge must be readily accessible so that errors can be detected and used as a basis for further learning. The current information structure supporting fire management was designed to support the 10 a.m. policy and is inadequate to support current policy. Expert systems and other recent developments in artificial intelligence can provide the necessary means to develop an accessible repository of current knowledge. Third, the inherent uncertainty and risk surrounding possible future outcomes must be displayed. Bayesian decision analysis can be used to deal with uncertainty and risk. Fourth, balanced policies must be designed. These must provide for resource production and protection while creating opportunities to develop better understanding. Signal detection theory and receiver operating characteristic curve analysis provide tools to help design balanced policy. These concepts are illustrated by applying them to the problems surrounding wilderness fire management and the need for long-range fire danger information.

INTRODUCTION - SEEKING A BALANCE

The need to balance competing and often conflicting objectives is a problem whenever policy is being made. In resource management, there is often the need to balance utilization with preservation. The disputes about wilderness designation and forestry activities in spotted owl and red-cockaded woodpecker habitats are controversies in search of a balance point. Several aspects of fire management require a balance. In wilderness fire management, the role of fire in perpetuating disturbance regimes in near-natural landscapes must be balanced with the necessity of protecting resources that would be damaged by fire. In smoke management the use of prescribed fire must be balanced with minimizing the nuisance of smoke. During periods of high fire danger, shutting down the woods to protect them must be balanced with the need to keep the woods open for people who earn their livelihood there. At the interface between wildland and urban areas, it is necessary to balance the threat of wildfire and the costs of risk-reduction measures. How should government regulatory agencies go about determining the balance point? And how can they describe their search for balance and its results to affected parties?

ADAPTIVE RESOURCE MANAGEMENT

Adaptive resource management (Clark 1989, Holling 1978, Saveland 1989, Thomas and others 1990, Walters 1986) recognizes the fact that the knowledge we base our decisions on is forever incomplete and almost always shrouded in uncertainty. Management is a continual learning process that evolves by learning from mistakes. Several authors have expressed the importance of learning from failure. "You have to accelerate the failure rate to accelerate the success rate" (Peters 1987). "Intelligent error needs to be tolerated.

Multitudes of bad ideas need to be floated and freely discussed, in order to harvest a single good one" (Toffler 1990). "The willingness to risk failure is an essential component of most successful initiatives. The unwillingness to face the risks of failure--or an excessive zeal to avoid all risks--is, in the end, an acceptance of mediocrity and an abdication of leadership" (Shapiro 1990).

Designing adaptive policy involves four tasks. First, the management problems must be defined and bounded, often in terms of objectives and constraints. There is an increasing awareness of the need to define resource problems from a landscape perspective (Forman and Godron 1986, Naveh and Lieberman 1984). With the proliferation of geographic information systems, the importance of defining and bounding problems at the landscape level will become even more apparent.

Second, existing knowledge must be readily accessible so that errors can be detected and used as a basis for further learning. Walters (1986) used models to represent existing knowledge. The field of artificial intelligence, especially knowledge-based systems, provide additional capability to capture knowledge (Saveland 1990).

Current fire information systems are inadequate. Most, if not all, fire information systems were designed to support the 10 a.m. policy and do not adequately deal with the complexities of modern fire management. Fire occurrence reports track the efficiency of the suppression effort. When policy was changed to allow prescribed natural fires, only half of the fire occurrence report form for the Forest Service had to be filled

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out for these fires. These reports provide almost no useful historical information for managing wilderness and park fire management programs. In addition, adequate cost data is severely lacking, preventing useful economic analysis. Structure and site characteristics in the wildland urban interface are not recorded, preventing analysis of structure losses. The national weather data library is known for its missing and questionable data. Currently, there are no links between national fire occurrence databases and fire weather databases. Entrepreneurial fire managers have been able to download the data into relational databases to conduct analysis. In addition, there are plans to convert the national databases into a relational form. Forest Service fire occurrence data resides in Fort Collins while Park Service data resides in Boise in different formats, further complicating the sharing of data and historical analysis. Prescribed burn plans exist in paper copy or as a word processing document on a computer, the vast historical information largely inaccessible, tucked away in personal file cabinets. The collapse of wilderness and park fire management during the summer of 1988 was not so much a failure of policy as a reflection of an outdated information system's inadequacy to support fire management decisions in today's complex world. Information needs analysis have been conducted recently and the situation is rapidly changing for the better. In addition the coming explosion of GIS technology, with the shortage of spatial data, will improve the situation dramatically.

Third, uncertainty and its propagation through time in relation to management actions must be addressed. Fire managers all too often live in a fairytale world of deterministic models that ignore uncertainty. Bayesian decision analysis offers one means of coming to terms with the inherent uncertainty and risk.

Fourth, balanced policies must be designed. These must provide for continuing resource production and protection while simultaneously probing for more knowledge and untested opportunity. Signal detection theory provides one mechanism to help design balanced policies.

WILDERNESS FIRE MANAGEMENT - AN EXAMPLE

Signal detection theory (Egan 1975, Saveland and Neuenschwander 1990, Swets and Pickett 1982, Wilson 1987) divides a decision problem into three parts: state of nature, response, and outcome (fig. 1). State of nature refers to presence or absence of a signal at the time a person makes a response. The signal is either present or absent. Responses are alternative actions decision makers must choose between. Decision makers can control their response, but have no control over the state of nature. They can respond by saying that they detect signals or that they do not. The point where a person switches between responding yes and responding no is the threshold of evidence. If the signal strength is greater than the threshold of evidence, the response is yes. If signal strength does not reach the threshold of evidence, decision makers will not detect the signal and the response will be no. The threshold of evidence can be varied. As the threshold of evidence is increased, a person is more likely to say no, thus reducing the number of false alarms, but increasing the number of misses. As the threshold of evidence is decreased, a person is more likely to say yes, thus reducing the number of misses and increasing the number of false alarms. This inherent trade-off between misses and false alarms provides the opportunity to find a balance point. A response combined with a state of nature results in an outcome for which the decision maker has some level of utility. One of the strengths of decision theory is that it separates the decision from the outcome.

Response	State of Nature	
	Signal Present s	Noise n
Yes Y	HIT $P(Y\|s)$	FALSE ALARM $P(Y\|n)$
No N	MISS $P(N\|s)$	CORRECT REJECTION $P(N\|n)$

Figure 1.--The signal detection paradigm.

Response	State of Nature: Undesirable Fire	State of Nature: Desirable Fire
Initial Attack	HIT	FALSE ALARM (????)
Do not Initial Attack	MISS (Yellowstone '88)	CORRECT REJECTION

Figure 2.--Signal detection for wilderness fire.

The wilderness fire decision can be divided into two responses that combine with two states of nature to produce four possible outcomes (fig. 2). The decision maker could choose to suppress a fire that, had it been allowed to burn, would have eventually exceeded acceptable conditions (i.e. become a wildfire). This hit is a desirable outcome because money has been saved by putting the fire out when it was small. Second, the decision maker could choose to let such a fire burn, in which case it would have to be put out later. This miss is an undesirable outcome because the costs of putting out a fire increase exponentially as the fire's size increases.

Third, the decision maker could choose to put out a fire that, had it been allowed to burn, would not have exceeded acceptable conditions (i.e. would have stayed within prescription). This false alarm is an undesirable outcome because an opportunity to allow fire to play its natural role has been missed. Fuel management benefits are not realized, firefighters are exposed to unnecessary risk of injury, and unnecessary costs associated with the suppression effort are incurred. Perhaps most important, nothing is learned. There is no increase in knowledge. Although this block and the hit block can be discussed conceptually, they are counterfactuals, and there is no way to determine these blocks in reality.

Finally, the decision maker might choose to let a fire burn, and this fire would stay within prescription. This correct rejection is another desirable outcome. Fire is allowed to play its natural role in maintaining various ecosystems, benefits associated with fuel management are realized, and the costs of fire suppression are saved.

Thus, the strategy for wilderness fire management is to allow as many non-problem-causing fires to burn as possible. For fires that are expected to cause problems, quick suppression while the fire is small is necessary to minimize costs and damages.

Long-range assessments of fire danger are key factors when managers have to decide whether to suppress specific wilderness fires. The fire danger prediction task can also be put into a signal detection framework (fig. 3). When

Response	State of Nature: High Danger	State of Nature: Low Danger
Predict High	HIT	FALSE ALARM
Predict Low	MISS	CORRECT REJECTION

Figure 3.--Signal detection for long-range forecasting.

lightning ignites fires early in the season, there must be an assessment of what fire danger conditions are likely to evolve later in the season.

An analytical procedure called the receiver operating characteristic (ROC) curve is an inherent part of signal detection theory. The ROC curve is a plot of the percentage of hits on the Y axis against the percentage of false alarms on the X axis (fig. 4). An ROC curve summarizes the set of 2 x 2 matrices (fig. 3) that result when the threshold of evidence is varied continuously, from its largest possible value down to its smallest possible value. The upper left-hand corner, where the percentage of hits equals one and the percentage of false alarms equals zero, represents perfect performance. The positive diagonal, where the percentage of hits equals the percentage of false alarms, is what would be expected based on pure chance.

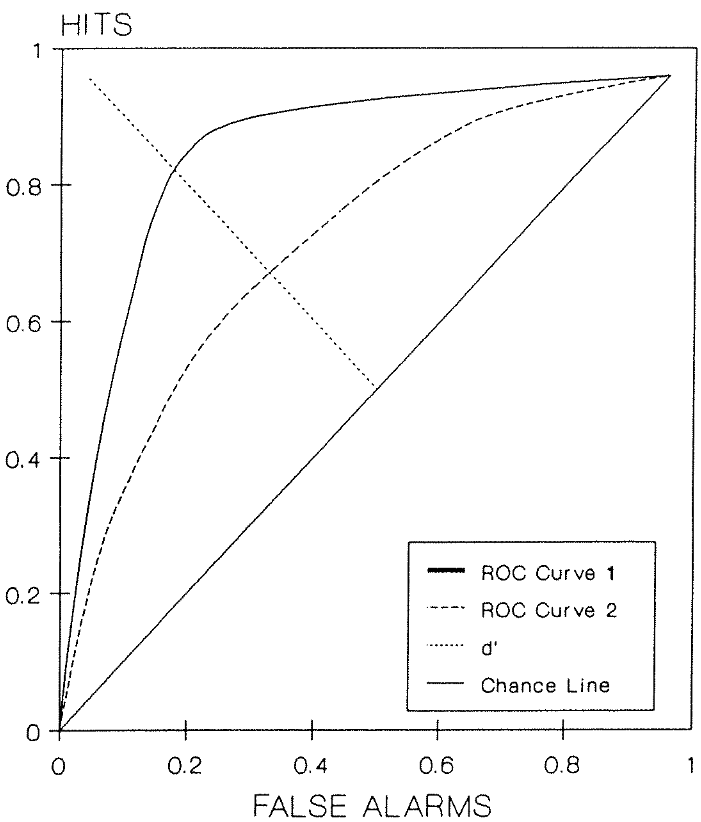

Figure 4.--Receiver operating characteristic (ROC) curves.

Various strategies can be used to select an appropriate threshold of evidence. One such strategy, minimax, attempts to minimize false alarms while maximizing hits.

The ROC curve has four important properties which correspond to the four tasks required to implement adaptive resource management. First, ROC analysis requires that the problem be defined explicitly. In this case, it is necessary to say just what constitutes high fire danger and what does not. In the example to follow, fire danger is defined in terms of the energy release component (ERC) of the national fire danger rating system. If the ERC at a certain date early in the fire season exceeds a threshold (predict high fire danger) and the ERC exceeds a critical value later in the fire season (late-season fire danger is high), the result is a hit. If the ERC early in the fire season exceeds a threshold but the ERC does not exceed the critical value later on, the result is a false alarm. Miss and correct rejection can be defined in a similar manner. The threshold varies to display the possible trade-offs. The critical value is site specific. The manager can select a critical value based on past experience. For example, noting that fires start to spread rapidly on north slopes, develop into crown fires, and become uncontrollable at a certain value, would be a suitable critical value. An explicit definition of fire danger and fire severity will enhance communication between fire staff and line officer decision makers, and between the line officer and the public. Second, the ROC curve displays skill prediction, or how much confidence to place in the prediction. A point near the chance line does not warrant much confidence, while a point close to the upper left-hand corner is reliable. The area under the curve is a measure of skill prediction and can be compared to chance. Skill prediction can also be considered a measure of our current state of knowledge. As more knowledge is obtained prediction systems should improve, and this improvement should result in new ROC curves that get progressively closer to the upper left-hand corner, which represents perfect prediction. Third, the ROC curve expresses the inherent uncertainty of the predictions in terms of Bayesian probability. Each point on the curve corresponds to percentages of hits, false alarms, misses, and correct rejections on a scale of zero to one. Fourth, the ROC curve displays the possible trade-offs between misses and false alarms as the threshold of evidence varies. A high percentage of hits is often possible only when there is a high percentage of false alarms. To reduce the number of false alarms often implies an increase in the number of misses. Selecting an operating point on the ROC curve is selecting a balance point.

Figure 5 is an ROC curve developed for the Westfork Ranger District weather station. The Westfork weather station collects data used by those who make decisions about prescribed natural fires in a portion of the Selway-Bitterroot Wilderness. Fire danger prediction is explicitly defined by a threshold ERC early in the fire season and a critical ERC later on in the season. A critical ERC value of 52 was chosen. During the period from 1973 to 1987, the ERC reached 52 in four of the fifteen years (1973, 1977, 1978, and 1979). Thus in 73 percent of the years, the ERC does not exceed 52 (low danger years), while 27 percent of the years, the ERC exceeds 52 (high danger years). The ROC curve displays percentages of hits and false alarms for threshold ERC values from 20 to 43. The probability that the ERC exceeds 29 on July 10 given that the ERC exceeds the critical

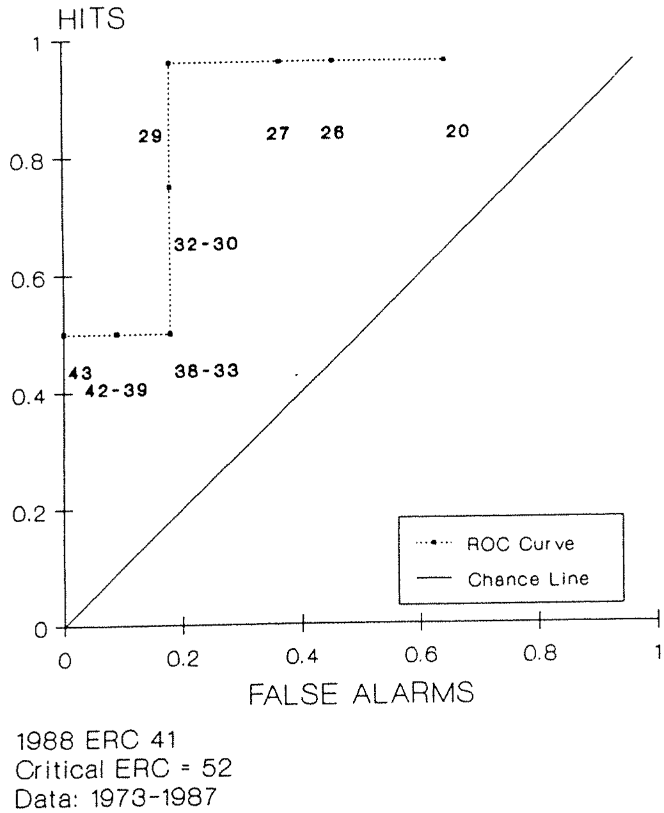

Figure 5.--Long-range ERC forecast for Westfork R.D. on July 10.

value of 52 later on in the fire season (hit) is 1.0. The probability that the ERC exceeds 29 on July 10 given that the ERC does not exceed the critical value of 52 later on in the fire season (false alarm) is 0.18. It follows that the probability of a miss at that point on the ROC curve is 0 and the probability of a correct rejection .82. Skill prediction is high. The area under the ROC curve is 0.91. If it were important to minimize the number of false alarms, the threshold of evidence could be increased to 43. This would reduce the number of false alarms by 18 percent, but would increase the number of misses by 50 percent. Saveland (1989) presents a similar analysis for Yellowstone National Park.

CONCLUSIONS

Most resource management controversies require seeking a balance between competing, conflicting objectives. Finding a balance is an integral part of adaptive resource management. Implementing adaptive policy involves four steps: defining and bounding the problem, representing current knowledge, representing the uncertainty surrounding our predictions of the future, and designing balanced policies that provide for resource production and protection while permitting experimentation aimed at increasing knowledge. Receiver operating characteristic curve analysis can assist adaptive resource management. ROC forces explicit definitions, represents current knowledge through skill prediction and readily displays uncertainty and possible tradeoffs.

Adaptive resource management points out the limits of our current knowledge and the importance of increasing our knowledge of the structure and function of natural resources. In fact, knowledge can be considered a resource. Surely our policies should promote the acquisition of new knowledge.

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PRESCRIBED FIRE AND VISUAL RESOURCES IN SEQUOIA NATIONAL PARK

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Abstract—The management goals at Sequoia National Park are to restore the fire climax ecosystems of the giant sequoia-mixed conifer forests to more natural conditions through the reintroduction of fire after many years of fire suppression. Objectives of prescribed fire must address the need for mitigation in "special management areas" (SMAs) that are under heavy impact from human use. The sensitive treatment of scenic resources in these SMAs can augment natural diversity if the structure of "naturalness" is given priority over uniformity of fuel load reduction. Management actions should seek to: (1) mimic natural fire patterns whenever possible; (2) avoid artificial infrastructure as burn unit determinants; and (3) conserve and enhance scenic resources in areas threatened by intensive human use. Visual resources were inventoried and management objectives recommended.

INTRODUCTION

Prescription fire began in the Giant Forest of Sequoia National Park in 1979. Since then several burns have been conducted. The management objectives of these burns have been primarily to reduce hazardous fuel accumulations and to restore the forest to a more natural ecosystem while sustaining populations of giant sequoias (*Sequoiadendron giganteum*) (NPS 1987a). The overall burn pattern on the forested landscape was originally designed to prevent or minimize the potential risk of a catastrophic fire sweeping over the Giant Forest plateau. In an effort to accomplish these objectives, park resource managers were charged with a variety of sometimes conflicting objectives An independent review was commissioned by then Director of the National Parks Service Western Region, Mr. Chapman in 1986.

The independent review of the giant sequoia-mixed conifer prescribed burning program of Sequoia and Kings Canyon National Parks by the Christensen Panel resulted in a report (Christensen and others 1987). Among many recommendations were instructions to explicitly address aesthetic concerns within the park's "Showcase" areas. The Sequoia Natural Resources Management Division has since changed the term "Showcase" to Special Management Areas. The Panel Report specifically recommended consultation with landscape architects in the development of burn plans with special emphasis on the SMAs.

Special Management Areas are located in the most heavily visited portions of the park. The three primary sources of visual impact within these areas that must be mitigated are the reintroduction of fire, visitor overuse, and overgrown thickets of non-fire climax species. The Sequoia and Kings Canyon Vegetation Management Plan (NPS 1987b) notes that SMAs are designated "where maintenance of natural processes is guided more by scenic concerns."

High visitation via roads and trails are a significant anthropogenic impact within an ecosystem that has management goals for 'naturalness'. The challenge of maintaining a natural aesthetic for this type of visitation is made compelling by the fact that roads and trails concentrate human impacts and have human facilities associated with them (food vendors, parking lots, restrooms, etc.). Current management goals of 'naturalness' are further complicated by historic cultural values that have developed over the past one hundred years since the establishment of the park. The named trees and logs have become 'cultural objects' along trails and roads, such as the General Sherman Tree and other named trees, groves, logs, and stumps in the Giant Forest. These areas of heavy visitation and subsequent substantial human impact must be managed more intensively and thus are termed SMAs.

As stated in the Panel Report (Christensen and others 1987), SMAs should not be seen as "static museums," created through "scene" management, but rather as a part of dynamic ecosystems, sensitively managed to preserve scenic and ecological resources. The Prescribed Fire Management Program (1987a) notes that the intention of management in these areas is not to apply a method of "greenscreening", whereby dramatically different appearing landscapes exist behind SMAs. Instead, these areas should be burned as more sensitive units with special attention given to specific goals and objectives for visual quality, environmental enhancement, and interpretation, as complemented by associated resource objectives.

The National Park Service Act of 1916 declared that "the fundamental purpose of [a National Park] is to conserve the scenery and, the natural and historic objects and the wildlife therein and to provide for enjoyment of the same in such a manner and by such a means as will leave them unimpaired for the enjoyment of future generations." Interpretation of this mandate has clearly demanded a sophisticated level of

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management since the release of the Leopold Panel Report (Leopold and others 1963). The relationship between aesthetics, scenery, and natural process is a complex natural and cultural issue that continues to evolve and will do so through ongoing multidisciplinary research. Visual resources are a prime asset in our National Parks and they must be conserved and managed sensitively.

Preservation and restoration of natural ecosystems and their processes is important to maintain the dynamic character which ultimately formed the giant sequoia-mixed conifer forests prior to intensive human occupaion (Parsons and Nichols 1985). In the Giant Forest, aesthetic and ecological goals need not conflict, but should seek to complement each other as much as possible. It can be achieved by utilizing the recommendations from recent aesthetic research in Sequoia National Park (Dawson and Greco 1987). Most importantly, management should seek to mitigate the effects of past fire suppression and mimic natural fire patterns while educating park visitors about fire ecology.

Historically, the giant sequoia-mixed conifer ecosystem experienced frequent, low intensity fires (Kilgore 1987) which structured the forest prior to human interference. The effects of past management actions in suppressing all natural lightning fires, for some seventy-five years (possibly representing many natural cycles), has resulted in an altered forest structure and high ground fuel accumulation in many areas. The forest structure has been changed to favor shade tolerant fir and incense cedar (Harvey 1985; Kilgore 1985; Bonnicksen and Stone 1982; Bonnicksen 1975) while unnaturally high fuel accumulation risks increased mortality of giant sequoias and understory species during a fire. Past prescribed fires have resulted in what many environmental groups see as unnatural due to inadequate mitigative measures and procedures. Prescription fires are now designed to mitigate these effects through "cool burns" meant to restore natural conditions. The overall concern in SMAs is to have the forest "look" like a low intensity natural burn has moved through the forest even though the fuel load may have the potential for a high intensity fire; and environmental degradation through intensive use may not have the potential for recovery without active mitigation.

RESEARCH PROCEDURES AND METHODOLOGY

The procedures applied in this research were determined by the specific needs of management and recommendations from the Panel Report (Christensen and others 1987). They are (1) to delineate the viewshed boundaries of the SMAs, (2) to inventory and conduct an analysis on the visual resources within the SMAs, (3) to recommend ecologically acceptable visual resource management goals and objectives, and (4) to recommend management treatments to fulfill the visual quality goals and objectives.

The research consisted of an inventory of visual resource elements, formulation of goals and objectives, and development of a set of guidelines for the treatment of fire effects on the character of the landscape and on the character of individual giant sequoia features. The methodology developed for assessing the visual resources at Sequoia National Park can be applied to all roadways and trails within the park. The process model (fig. 1) graphically depicts the recommended methodology for SMA visual resource planning.

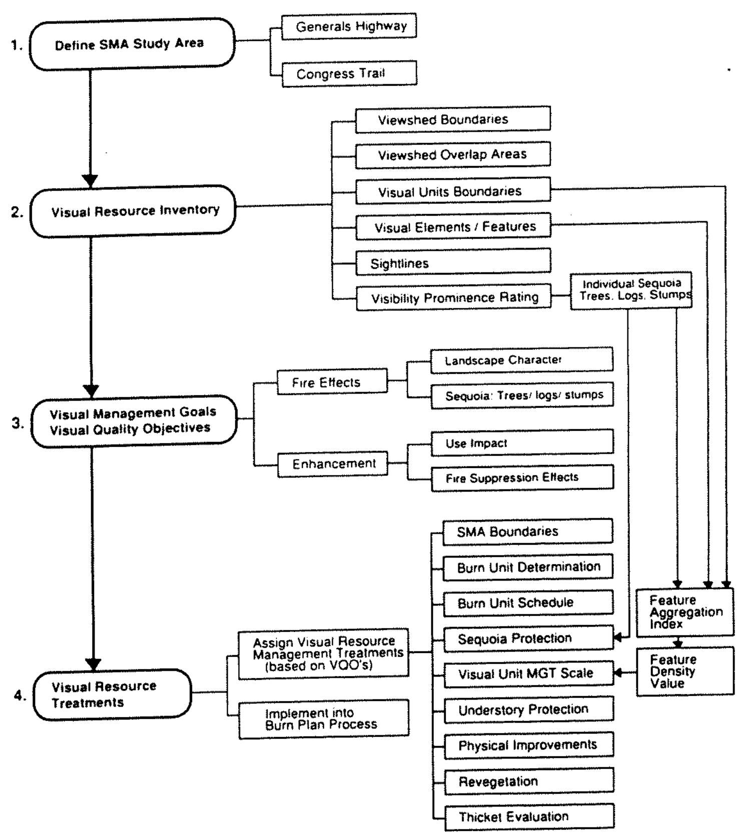

Figure 1.--Visual resource research methodology and planning approach.

SMA BOUNDARY DELINEATION

The study areas within the SMAs are defined in terms of their respective viewshed boundaries. A viewshed, or visual corridor, is a routed (by road or trail), physically bounded area of landscape that is visible to an observer (Litton 1979). A viewshed delineates the dimensions of the "seen" environment in terms of visual penetration. The viewshed boundary is formed from the dynamic composition of viewing points on a continuum (i.e. a road or trail). The viewing points are representative of a number of observer positions accounting for several viewing orientations (Litton 1973, 1968).

VISUAL RESOURCES INVENTORY AND ANALYSIS

An inventory of visual resources is a descriptive field survey that identifies the seen areas, and physically locates visual and perceptual elements within the selected SMA study areas. It consists of several parts including viewshed delineation, areas of viewshed overlap, visual unit delineation, identification of special features and visual element subunits, determination of giant sequoia visibility through a visual prominence rating, and the location of impacted views due to fire suppression. An inventory was surveyed and compiled for each study area SMA.

The goal of the feature analysis is to provide park managers with a tool to assess the relative difficulty of achieving the visual quality objectives. The Management Scale provides an indexed classification for each visual unit to indicate pre-burn planning intensity and (burn) labor requirements that will be necessary for any given burn unit. For example, in an area with many visual features (i.e., giant sequoias, logs, etc.) the Management Scale value could be rated as class "1" and an area with few visual features could rate as a class "4" value. Hence, if a burn unit contains several class "1" values, then more labor will be required to mitigate excessive fire effects. Formulation of the Visual Unit Management Scale consisted of five steps: a tabulation of features per visual unit; a feature aggregation index calculation; determination of visual unit acreage; a feature density value calculation; and an indexed classification of those values into the Visual Unit Management Scale values.

SMA VISUAL MANAGEMENT GOALS AND VISUAL QUALITY OBJECTIVES

Fire management planning in SMAs requires the development of clear goals and specific objectives as a critical step in the prescribed fire planning process (Fischer 1985; Bancroft and others 1983). Clear exposition of goals and objectives is necessary to evaluate the effectiveness of management actions. Management goals should be broad in scope and attainable through specific objectives that address issues within each goal. The three central issues for visual quality goals and objectives are (1) fire effects on the character of the landscape, (2) fire effects on individual giant sequoias, and (3) enhancement of currently affected visual resources.

Fire Effects on Landscape Character

The giant sequoia-mixed conifer forests have evolved in context of frequent fire return intervals and low fire intensities (Kilgore 1987; Van Wagtendonk 1985). Less frequent, more extensive and intense events, though, have also played an important role in this ecosystem. Kilgore and Taylor (1979) found through tree ring analysis that historical fires near the Giant Forest area were frequently small in size and generally confined to a single slope or drainage. They also report that fires ranged in size between 0.001 ha to 16 ha. In the same study area, Harvey and others (1980) confirm the small nature of these burns, suggesting they were about 10 ha.

In the Redwood Mountain area, the Kilgore and Taylor study (1979) also found fire return intervals on west-facing slopes to be about every 9 years, and on east-facing slopes to be about every 16 years. They also report mean fire-free intervals of 5 years on dry ridges of ponderosa pine and 15-18 years in moist sites of white fir. The average maximum fire-free interval was found to be 14-28 years. Their data also reveals that some clusters of giant sequoias have escaped fire for up to 39 years. Some areas may have escaped fire for a hundred or more years.

Restorative SMA prescription fires should be planned within an appropriate temporal and spatial framework. The juxtaposition of prescribed burns can greatly enhance or detract from the visual and ecological diversity of the forest. The goal should not be to create burns that result in large scale areas of an early successional stage. Rather, management burns should concentrate on maintaining, or creating, successional diversity throughout the forest (Harvey and others 1980). Fire should be introduced on a gradual spatial and temporal basis to restore the forest to a more natural state. Although reducing fuel accumulations is important, it is not necessary that this be the immediate objective of an SMA burn. Small-scale burns should be designed to maintain ecological and visual diversity over appropriate time scales. Planning should incorporate available site-specific fire history research.

To preserve successional and visual diversity, management plans should include small-scale burns, random juxtaposition of burns (a variety of burn contrasts), selected retention of understory vegetation, and limiting the number of burn units treated each year. Planned variation in future burn unit boundaries will also help maintain an ecologically and visually diverse park environment. To increase visual diversity and maintain a sense of ecological continuity along travel corridors, burn unit boundaries should cross roads and trails in some areas and remain adjacent to them in others. If roads and trails are always used as boundaries, one side will always appear different than the other. Human infrastructure should be avoided or limited as burn unit determinants. Because it could lead to a confused perception of the forest to some visitors and contribute to a less naturalistic aesthetic. Extended long-range plans, or areas in need of a second prescribed burn, should include variation in the boundaries of the first prescribed burn, or possibly the relocation of trails during this planning process. It is not recommended that the same boundaries be used for future burns. The return of fire should also be variable, both spatially and temporally. Variation is another very important aspect of visual and ecological diversity, as pointed out in the Christensen Report (1987).

Treatments of designated SMA burn units should be "cooler" prescriptions as noted in the Grant Tree SMA plan (NPS 1980a). Taylor and Daniel (1985) confirm that fire intensity correlates with scenic quality and recreational acceptability in ponderosa pine forests. They found that in comparison to unburned areas, low intensity fires produced improved scenic quality ratings after 3-5 years, but that high intensity fires "seriously declined" in scenic quality ratings after the same time period.

Efforts to provide a high value interpretive program are essential to educate the public about fire ecology and the aesthetic implications of fire ecology in the Giant Forest SMAs. The program is important because visitors are barraged with fire danger signs as they approach the park. McCool and Stankey (1986) found that visitors who were confused and uncertain about the effects of prescribed fire were afraid that it could be "detrimental" and negatively impact the park, but that visitor center exhibits and guided tours help engender an understanding and appreciation of the dynamic processes of forest succession and fire ecology. Roadside and trailside interpretive displays in appropriate locations, with descriptive graphics facilitate this objective. The Hazelwood Nature Trail is an excellent example. Hammit (1979) indicated that the value of interpretive displays located in visually preferred areas can be more rewarding and more likely remembered. Proper placement of displays in the environment appears to aid in the memory process of park visitors.

Fire Effects on Individual Giant Sequoia Trees, Logs and Stumps

Visual features in the Giant Forest are highlighted by the grandeur and presence of a high density of giant sequoias. As a result of this density and the park's design, visitor appreciation of the giant sequoias has rendered many of them as unique natural/cultural objects in the landscape. Hammit (1979) reports that the most remembered scenes by visitors are characterized by visually distinct features. It appears there is a strong correlation between familiarity and preference of scenery. Familiarity is highest in both most preferred and least preferred scenes, indicating that visitors are affected by both positive and negative features observed in landscape experiences.

Since the giant sequoias are a primary visual resource in the Giant Forest, the most visually prominent trees should receive the greatest scenic mitigative measures to retain a natural visual character following restoration burns. Maintaining high scenic and recreational values in the Giant Forest requires sensitive visual resource planning of fire effects and a strong interpretive program to effectively communicate fire ecology to the public. It was recommended that a management goal for the visual quality of distinct foreground features receive judicious burning around the bases of the SMA giant sequoias. The foreground trees have the dual distinction of being most impacted by intense human use and are also visually vulnerable.

Protecting all visible trees from intensive fire effects is not desirable. For visitors to gain a sense of appreciation for a wide range of fire effects, some of the less visibly prominent trees could provide an opportunity for such diversity. It is not intended that foreground trees should be protected at the expense of background giant sequoias. Rather, foreground sequoias should receive more sensitive treatment due to their proximity to high human use pressures and park infrastructure. Intense human use proximate to these trees has resulted in decreased duff cover, soil compaction, increased erosion, and lack of understory regeneration. Many of these trees are under unnatural stress. Background trees receive wilderness standards for giant sequoia management.

To gain better insight and understanding of visitor sensitivity to singeing and charring on highly visible giant sequoias, a special study would have to be conducted. A study has been completed (Quinn 1989) of visitor perceptions of recent prescribed fire management in Sequoia National Park and generally, visitors were not adverse toward fire scars. However, no research was conducted on reaction to singeing versus charring in recent burn units within the park.

The last issue regarding protection of individual giant sequoias is the maintenance of ecological and visual/cultural values associated with horizontal features in the forest landscape experience. The preservation of a select number of highly visible sequoia logs (in addition to named logs) along trails and roadways has been strongly recommended by some groups (Fontaine 1985). The interpretive value of these logs stems from the direct "involvement" the public has with these elements. The tactile experience of touching and passing under these logs can engender a strong appreciation for the grandeur of the giant sequoias. They also demonstrate the dynamic nature of succession in the giant sequoia-mixed conifer ecosystem. Hammit (1979) suggests that prolonged contact with such features increases familiarity. It was recommended that a balanced number of strategically located logs be protected from intense prescribed burns.

Currently Affected Visual Resources

Scenic resources are currently impacted by (1) intensive recreational use, and (2) the structural changes of vegetation in the giant sequoia-mixed conifer forest. The first is due to the effects of visitor overuse and the lack of facilities to accommodate the use volume. The second impact results from fire suppression which promotes the growth of shade tolerant conifer thickets (non-fire climax species) that limit the visibility of numerous giant sequoias within the viewshed. Management goals to alleviate both of these impacts would enhance the overall experience of the park.

Many high visitation areas such as the Congress Trail, General Sherman Tree, and Hazelwood Nature Trail suffer from severe overuse. Strategic signage in these areas is essential to better guide foot traffic (trampling) in these areas which has caused the disintegration of duff and subsequent erosion of surface soil. As a result, dusty or muddy visitor environments have inadvertently created biological and visual resource problems. Problems include erosion around the bases of sequoias exposing fibrous roots, erosion and decay of asphalted edges in parking areas and on trails, and a lack of understory vegetative cover due to trampling and soil compaction. Means to reduce these effects focus primarily on redirecting foot traffic in and around facilities and reducing trampling around the trees.

The second issue concerning enhancement of affected visual resources is the extensive growth of shade tolerant conifer thickets (non-fire climax species) resulting from fire suppression and disturbances due to road, trail, and facility construction (NPS 1980b; Bonnicksen 1985). In the absence of regular fire disturbance cycles, these thickets have grown unchecked by natural process, thus hindering the ability of the giant sequoia to reproduce successfully and also blocking both historic views and potentially valuable views of the giant sequoias in the Giant Forest SMAs. In addition to these problems, the thickets also represent future fuel load and fuel ladder problems. The visual resource goal should be to conserve scenery which enhances visitor experience within the SMAs through active management of the thickets. The means to achieve this goal is the limited strategic removal of these "overrepresented aggregation types" (Bonnicksen 1985; Cotton and McBride 1987).

VISUAL RESOURCE TREATMENTS

The recommended treatments consists of a Landscape Management Plan and a set of guidelines for visual resource management in the SMAs. Visual resource treatments are management actions designed to fulfill management goals and visual quality objectives. A photographic monitoring program is also recommended.

Landscape Management Plan

The SMA Landscape Management Plan identifies proposed burn units, planning units, past prescribed burns, burn exclusion areas and thicket problem areas. The burn units have been designed in accordance with the visual quality objectives to maintain a diverse visual character within the SMA study areas. Sections requiring additional research studies are classified as "planning units" and "SMA planning units" on the plan. Small areas of cultural value that are recommended for exclusion from prescribed fire are also indicated on the plan. Additionally, thickets that block views of giant sequoias, and thickets that present future visual resource problems are identified for treatment. Finally, measures to protect visually prominent giant sequoias are based upon the visual prominence ratings are shown on the Visual Resource Inventory maps.

Protection of visual elements is also meant to preserve pockets of mature understory vegetation in addition to giant sequoia protection. These pockets are ecologically important because intensive human use interferes with regeneration and colonization sources which are needed to avoid further damage and are needed as vegetative use buffers. These, too, are identified on the Visual Resource Inventory Maps. The analysis of visual features within the visual units provides a guide for resource managers to evaluate planning for labor requirements when planning burn units. A feature "density" value was generated for each visual unit and broken down into management intensity classes.

Burn Unit Design and Schedule

Burn units were designed based on the Fire Effects Guidelines for SMA Landscape Character. Natural boundaries for the SMA burn units are preferred to man-made boundaries in the design. It is recognized that it is essential to use roads and hiking trails in many cases due to economic constraints. However, alternatives to their use should be used where possible, such as streams, drainages, ridges, old fire lines, meadows, rock outcrops, and new fire lines.

The burn units in a maintenance fire regime should be varied from previous prescribed burns. It is not recommended that the same burn unit boundaries be used more than once if they are unnatural boundaries (trails or roads). Using the same boundaries runs an ecological and visual risk of creating an unnatural mosaic of forest succession. The maintenance burn regime units should concentrate on natural fire breaks that travel across trails instead of being bound by them.

Timing of the burn units is a very important aspect of planning. The burn units have been designed to restore the Congress Trail and the SMA section of the Generals Highway to more natural conditions. Following the restoration burn regime, a long-term maintenance fire regime should be formulated for the Giant Forest. It is recommended that this regime be based on area-specific fire history research.

A computer geographic information system (GIS) would greatly enhance the analysis and planning of the burn units in the Giant Forest because it is a very useful tool for evaluating large spatial data sets and many variables.

Guidelines for Thicket Problem Areas

The visual quality objectives regarding enhancement are designed to increase the visibility of giant sequoias affected by extensive thicket growth throughout SMA viewsheds. These thickets are blocking numerous potentially valuable views of giant sequoias (fig. 2). Management for a natural aesthetic and increased visual penetration into the forest within the SMAs warrants judicious mechanical thinning of some of these thickets (Bonnicksen and Stone 1982; Christensen 1987; Cotton and McBride 1987).

Figure 2.--Thickets of mixed conifers are encroaching on the views of giant sequoias due to the disturbance of road construction.

The thickets were mapped on the SMA Landscape Management Plan in two ways. Existing "blocked" views were mapped, and visually "encroaching" thickets are also shown. The encroaching thickets did not present a visual problem at the time the field work was conducted, but will cause visual penetration problems in the near future. They should be monitored photographically and evaluated for mechanical thinning. It was recommended that this be incorporated into the park's Vegetation Management Plan for the development zone (NPS 1987b).

Guidelines for Giant Sequoia Fire Effects Mitigation

As discussed in the visual quality objectives, it is the visually prominent trees which are impacted most by human use pressures. Park infrastructure, such as trails, roads, signs, restrooms, etc., are proximate to the visually prominent trees. The most valuable scenic resources are also the most visually prominent trees. Mitigative measures to protect these trees are critical in terms of ecological, scenic, and park infrastructure resources . The objective is not to leave these trees unburned, but to mitigate fire effects. Trees impacted by intensive human use are under stress and unsuppressed fire risks unnatural mortality. The four categories of giant sequoia protection (mitigation measures) are illustrated in figure 3 and include: (1) scorch exclusion, (2) minimal scorch, (3) limited scorch, and (4) unsuppressed scorch (within standard management tree protection guidelines). These relate directly to visual proximity as well as distance from human impact (Dawson and Greco 1987).

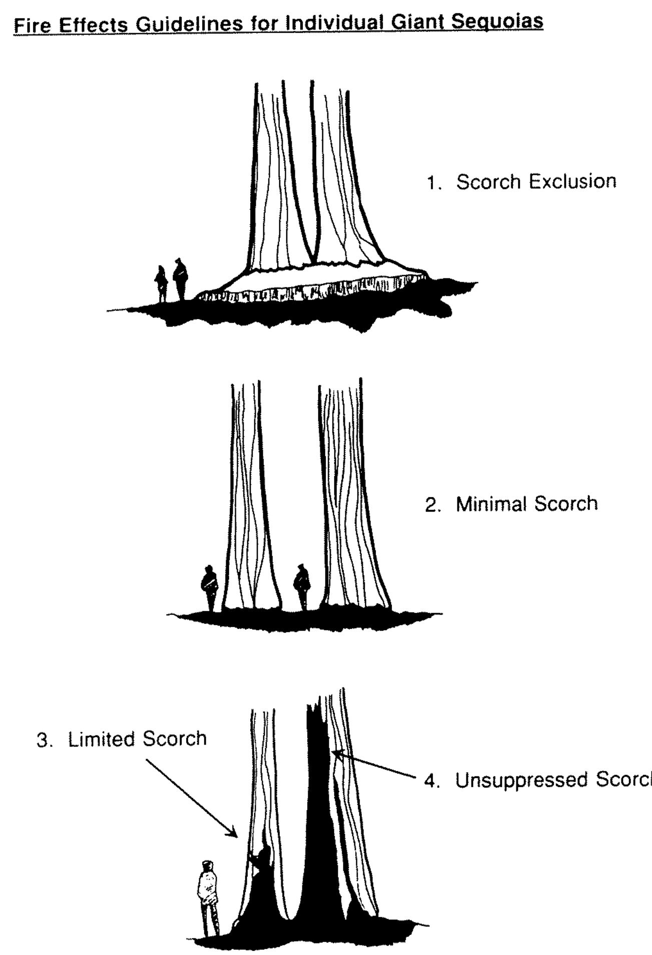

Figure 3.--SMA mitigation measures for giant sequoias.

To understand properly the descriptions of the four categories of giant sequoia protection, definitions of scorching, singeing and charring are necessary. In this study, "scorching" is the singeing or charring of sequoia bark. "Singeing" is bark ignition to a depth under one half an inch ($< 1/2"$). "Charring" is defined as bark ignition to a depth over one half an inch ($> 1/2"$). The question of singeing is not an intense aesthetic issue because park visitors seem to accept some fire damage to sequoias (Quinn 1989). However, reaction to varying levels of charring is undetermined and can impair the scenic quality of giant sequoias for longer time periods if the trees are under stress. Therefore, it was recommended that scorch and char guidelines be established in addition to current tree preparation standards (pre-fire) and firing techniques. It should be remembered that the guidelines apply only during the restoration prescribed fire phase.

Guidelines for Understory Protection

Planned retention of understory vegetation pockets is recommended in the SMA burn units. They offer opportunities to maintain visual and ecological diversity while increasing the probability of regeneration by providing colonization sources. Often, these pockets grow among rock outcrops and probably have escaped fire for longer periods under more natural ecosystem conditions. Historically, natural burns have undoubtedly missed many areas creating a mosaic of vegetation characteristic of the sequoia-mixed conifer ecosystem. The most obvious pockets for retention would be growing among rocks that could be supplemented with fire lines to lengthen their presence.

For aesthetics, these groups of plants provide a visual focus, diversity of elements, and demonstrate the scale between visitors and the large-scale giant sequoias and older conifers. Some good examples in Giant Forest are the native dogwoods (*Cornus nuttallii*) and Sierra chinquapin (*Castanopsis sempervirens*), and greenleaf manzanita (*Arctostaphylos patula*). Although some are adapted to fire and resprout after a fire, their rate of growth is slow. Their visual qualities and interpretive qualities could be diminished for many years.

DISCUSSION

There has been concern on the part of National Park Service scientists about some of the research recommendations on visual resources (Dawson and Greco 1987). An interdisciplinary group of staff from Sequoia National Park representing science, administrative management, visitor interpretation, fire management, and resource management met and forwarded comments. The following discussion presents these views as well as further discussion on the visual resource research.

NPS and Understory Issues

The NPS group does not favor "the deliberate retention of mature groups of understory plants, since prescribed fire tends to leave mosaics of burned and unburned areas, and the recovery of the understory plants in post-fire succession is an important part of the story of the forest" (NPS 1988).

At several prescribed burns in the Giant Forest, the visual resource research team observed that fire was applied homogeneously within the burn units. Fire management staff frequently burn areas completely and uniformly, and if fire bypassed any fuel loads, the fire technicians returned moments later to fire that area. This does not mimic natural fire patterns and as a result, pockets of understory plants rarely survive. The practice of multiple-spot firing after the fire has moved through should be modified to rely on this technique only in situations where absolutely necessary (greater than 1000-hour class fuels). Kilgore (1985) supported this concept by pointing out that increased uniformity and lessened mosaic pattern is unnatural.

Litton (1988) has written to Sequoia National Park that "In addition to modifying fuel concentrations, both down material and standing live trees, related to dominant specimens, I further urge protective measure for certain visually significant understory - ground floor components. Several obvious examples of these subordinate features are snags, fallen big trees and mature, tree-form dogwoods; these and others contribute significantly to experiencing a rich landscape, are signs of time and succession, and represent considerably more than fuel needing to be burned."

Litton further added, "Brewer, King, and Muir confirm and give emphasis to other contemporary accounts that the Sierra Nevada forest were [sic] impressive for their [sic] openness and for the large scale of mature trees. At the same time, these three early observers note the diversity of what they saw in the various forest and woodland species, their associations, regeneration and some of the ground plane and understory characteristics. Brewer notes species or type distribution in space and elevation, the combinations of the mixed conifers - some with Big Trees, the array of ages and sizes in Big Trees, [and] the significance of fallen Big Trees in appreciating their size and age. King emphasizes the impact of contrasts found in the association of Big Trees and Sugar Pine and White Fir as well as the experience of the spatial quality found in the open forest. Muir comments on openness, on spatial distribution, on the smooth floor, but also points to the contrast of underbrush with Big Tree bark and speaks in considerable detail about Big Tree regeneration. Diversity, then, appears to be an historic clue about the historic forest in addition to the frequently stated perception of openness."

NPS and Visibility Issues

The NPS group "was unanimously opposed to allowing changes in appearance due to fire only in the medium and low visibility trees, while retaining foreground trees in their present unburned state... in general, all trees regardless of [visibility] rating will be prepared and burned according to current standards..." (NPS 1988).

In the visual resource recommendations, scorch exclusion does not mean "unburned". More importantly, it will be very difficult to treat focal point trees, such as the General Sherman Tree, with prescribed fire. These trees are surrounded by trails, fences, facilities, and/or roads and are also subject to intensive visitor use and abuse. Most foreground trees in special management areas are stressed by pavement, soil compaction and altered topography. As one moves farther from view corridors, this type of impact (direct human disturbance) is lessened. It is evident that there is an ecological relationship between aesthetics and the built environment and treating giant sequoias in the foreground more sensitively than those further away actually recognizes the impact of these conditions.

NPS and Downed Log Issues

The NPS Group agreed "that logs identified by interpretation as having cultural or interpretive value will be protected from fire. However, no effort should be made to preserve logs as horizontal elements, since these logs are important sources for seedbeds, which are an important part of the forest story. In addition, the SMA burn units are small, and it is not likely the loss of logs will produce an impact on the visual resources of the area as a whole" (NPS 1988).

The Yellowstone fires document that horizontal elements (logs) are increased by fire, not decreased, regardless of fire intensity (Ekey 1989; Guth 1989; Simpson 1989). Although it is difficult to compare Yellowstone and Sequoia, logs are universally important ecologically and visually for the maintenance of habitat diversity. It is important to avoid the homogeneous burn coverage typical of hot fires in unnatural fuel accumulations. While totally burnt logs can play a role in sequoia regeneration, firing techniques which attempt to burn all logs does not recognize that some logs also play an important role in the nutrient cycling of the forest by acting as nutrient reservoirs and reducing soil erosion following a fire. If the fire burns a log as it moves through, this seems acceptable. The problem is when fire crews return to spot-burn a log that the fire has by-passed.

NPS and Thinning Issues

The NPS group "agreed that existing vistas of the Sherman, Grant, and McKinley trees should be preserved. The group was opposed to pre-burn thinning of trees which obstruct sequoias as well as to the suggestion that trees killed by the fire should be cut out" (NPS 1988).

In discussing visual resources, the thickets are diminishing the scenic value of the park from roads and trails. Many of these thickets are less than fifty years old and exist as a result of managed fire exclusion and site disturbance, such as road construction. This abundant growth impacts scenic resources and ecological processes. Kilgore (1987) states that "removing fuel from the intermediate layer between between surface and crown fuels greatly reduces the potential for high intensity surface fires that could lead to crown fires." Under a more natural fire cycle, crown fires are a relatively rare event in the giant sequoia-mixed conifer ecosystem and would be an unnatural and unfortunate consequence of the fuel load build-up due to past fire suppression.

The Christensen Report (1987) indicates approval of 'judicious pre-burn cutting of understory trees...where ignition of such trees might have a negative effect on stand appearance and/or when their removal would enhance the visual effect of adjacent specimen trees."

CONCLUSION

Past human interference with the ecosystem of the giant sequoia-mixed conifer forests has impacted the visual and ecological resources in Sequoia National Park. These impacts have been augmented by concentrated visitor pressure in the areas of the park with roads, trails, and built facilities. Special management areas have been established to address these complex management problems of balancing cultural and natural ecosystem interests.

The detailed visual resource database and mitigation guidelines developed for the Prescribed Fire Management Program were designed to provide park resource managers with new tools to achieve more natural fire effects for the landscape and giant sequoia visual resources. There were forty-four separate treatments recommended with roughly half of the recommendations known to be implemented (Dawson and Greco 1987). It is pleasing and appreciated that support was so forthcoming from the National Park Service for over half of the treatments. This paper has attempted to explore the complexities of the remainder. However, creating favorable conditions for the perpetuation of the giant sequoia is supported and current management policies using prescribed fire management are improving continuously. The visual resource research has strived to present ecologically acceptable solutions to problems of culture in the context of a natural environment and the role of fire in the giant sequoia-mixed conifer ecosystem which support this continued improvement.

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GIS APPLICATIONS TO THE INDIRECT EFFECTS OF FOREST FIRES IN MOUNTAINOUS TERRAIN

David R. Butler, Stephen J. Walsh, and George P. Malanson[1]

Abstract—Snow-avalanche paths and landslides are common geomorphic features in Glacier National Park (GNP), Montana, and represent hazards to human occupancy and utilization of the park. Forest fires have been spatially extensive there, and it is well documented that areas subjected to forest fires become increasingly susceptible to avalanching and landsliding.

The locations of all snow avalanche paths and landslides in east- central GNP have been mapped on topographic maps and verified. The avalanche paths have been digitized and entered into a geographic information system (GIS) using ARC/INFO. Digital elevation models and Landsat Thematic Mapper digital data were processed to create elevation, slope angle and aspect, and landcover GIS overlays. Merging of overlays illustrates areas of maximum erosion potential by snow avalanching and by landsliding in the event of a forest fire. Post-fire vegetational succession can be accommodated into the GIS to illustrate areas of high, medium, and low hazard from avalanching and landsliding.

INTRODUCTION

The western cordillera of North America experiences hundreds of thousands of snow avalanches and numerous landslides annually. Most snow avalanches follow well defined topographic indentations on the mountainous slopes (Butler, 1989). These snow-avalanche paths (fig. 1) are easily mapped at a variety of scales, so that hazard zones resulting from snow avalanching may be easily delineated (Butler 1979, 1986b, 1989; Butler and Malanson 1985; Walsh and others 1989). Mass movements of earth and rock material, or landslides for the sake of convenience, are also common in the cordillera. Steep terrain, seismic triggers, and unusual precipitation and snowmelt events produce widespread landsliding in the area (Butler and others 1986).

It has been well documented that forest fires geomorphically destabilize a burned area, making it more susceptible to erosion by both snow avalanching (Beals 1910; Munger 1911; Winterbottom 1974; Harris 1986) and landsliding (Swanson 1981; Morris and Moses 1987; Parrett 1987). The removal of forest cover particularly affects areas prone to snow avalanching. Most starting zones for snow avalanches are on fairly steep slopes of 30-45° (fig. 1). The forest cover in this environment provides a significant stabilizing influence on the snowpack, reducing the avalanche hazard. If a forest fire removes this stabilizing influence (fig. 2). expansion of the area of snow movement is likely to occur. This in turn can provide more frequent and larger, and therefore more dangerous, snow avalanches on the low- angle slopes near valley bottoms where roads, railroads, tourist facilities, and communities are likely to be concentrated (Munger 1911; Winterbottom 1974).

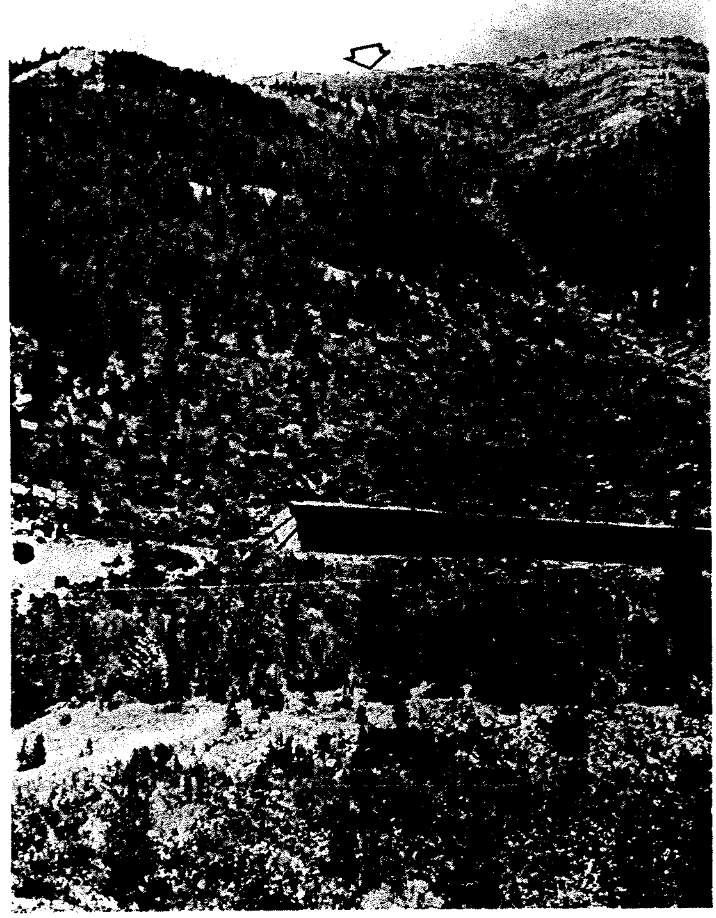

Figure 1. Typical snow avalanche path, southern Glacier National Park, Montana. Arrow points to location of figure 2. Note how lateral boundary of avalanche path exceeds the protective capacity of the snowshed, a result of destabilizing forest fires during 1910-1919. Photo by D.R. Butler.

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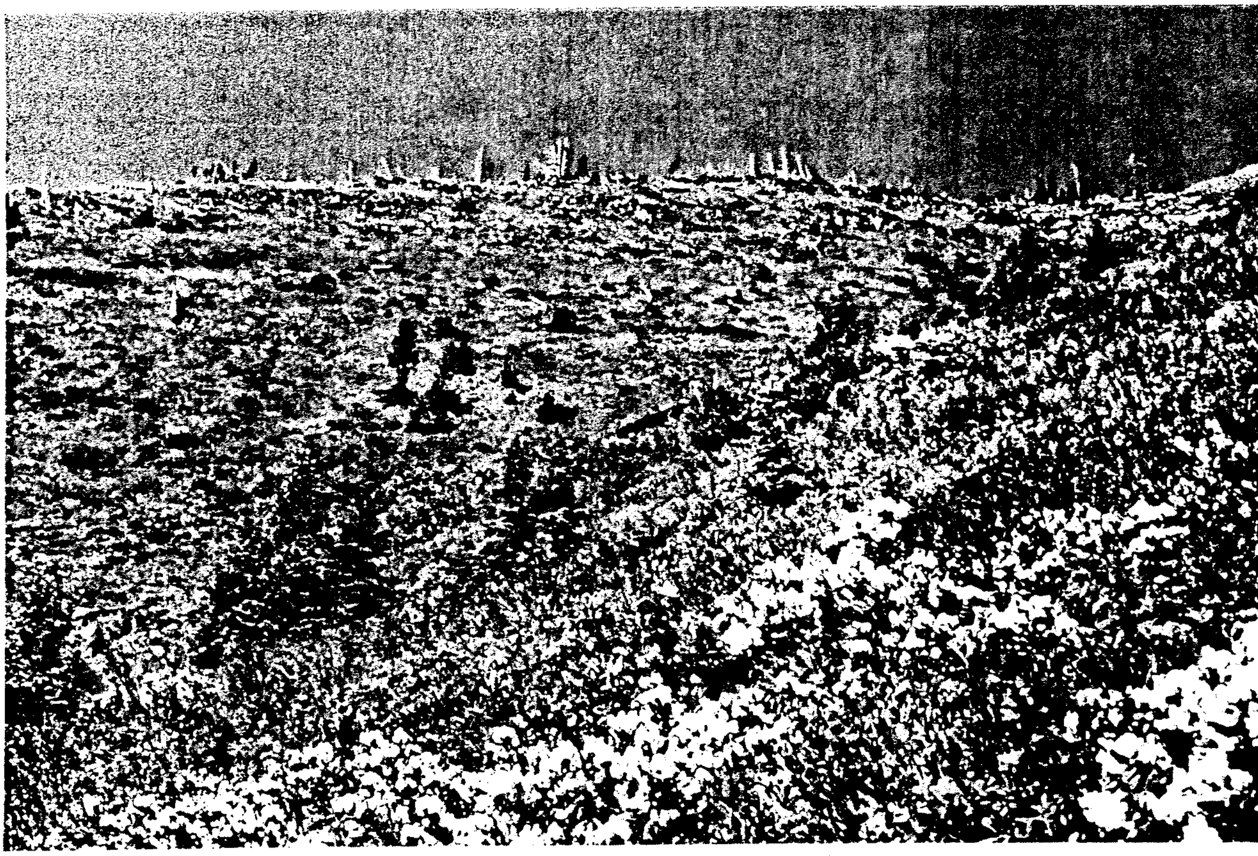


Figure 2. Burned-over starting zone of the Shed Seven avalanche path shown in figure 1. Dead snags are especially visible along the skyline. Photo by D.R. Butler.

Areas already susceptible to landsliding are also likely, in the event of forest fire, to experience reactivation of previously stabilized landslide deposits (Swanson 1981), and accelerated erosion on the surface of these deposits by running water will also occur (Morris and Moses 1987). Burned areas will also generate landslides whereas adjacent unburned areas do not (Parrett 1987). It is, therefore, of paramount importance in mountainous areas where tourism and multiple-use forestry form the economic base, to know where expansion of snow-avalanche paths, reactivation of landslides, and accelerated erosion is likely to occur in a post-burn scenario.

This study describes how a Geographic Information System (GIS) may be used to map and study snow-avalanche paths and landslides, and in turn how information on areas and year of burning by forest fires and the level of plant revegetation can be incorporated into the GIS. This allows the delineation of areas of potential expansion of snow avalanching and landsliding, as well as areas affected by less hazardous but geomorphically and environmentally significant accelerated surface erosion. This information can be used by forest and park management personnel who need to critically examine areas of sensitive habitat, or who may be in charge of hazard analysis in areas of heavy transportation and tourism. In addition, such information can be used to evaluate sediment movement and concentrations within hydrologic systems as a consequence of forest fires and snow avalanching or landsliding and their spatial/temporal distributions.

THE STUDY AREA

Snow avalanching and landsliding are common geomorphic occurrences in the Rocky Mountains of northwestern Montana. Forest fires of varying intensity and extent have burned broad areas susceptible to both avalanches and landslides. One area particularly susceptible to both avalanching and landsliding, a result of a set of unique topographic and geologic conditions, is Glacier National Park, Montana (Butler 1979; Butler and others 1986). This park, created by act of Congress in 1910, preserves approximately one million acres of wilderness which has never been logged.

Glacier National Park contains a mosaic of vegetational types dependent on such factors as elevation, slope aspect, position west or east of the Continental Divide which bisects the park, and fire history. Many historical fires have burned portions of the park before and since 1910 (see, for example, Beals 1910; McLaughlin 1978; Holterman 1985; Finklin 1986; Larson 1987). Until recently, it has been the policy of Glacier Park management to vigorously suppress all forest fires, whether natural or human- caused (Wakimoto 1984). The 1980s saw a shift in policy, with movement toward a management plan that would allow natural fire to play a role in the park ecosystem in designated areas.

Along the southern boundary of Glacier Park, several widespread forest fires occurred during the period 1910-1919 (Payne 1919). There, numerous snow-avalanche paths impinge onto the tracks of the Burlington Northern Railroad,

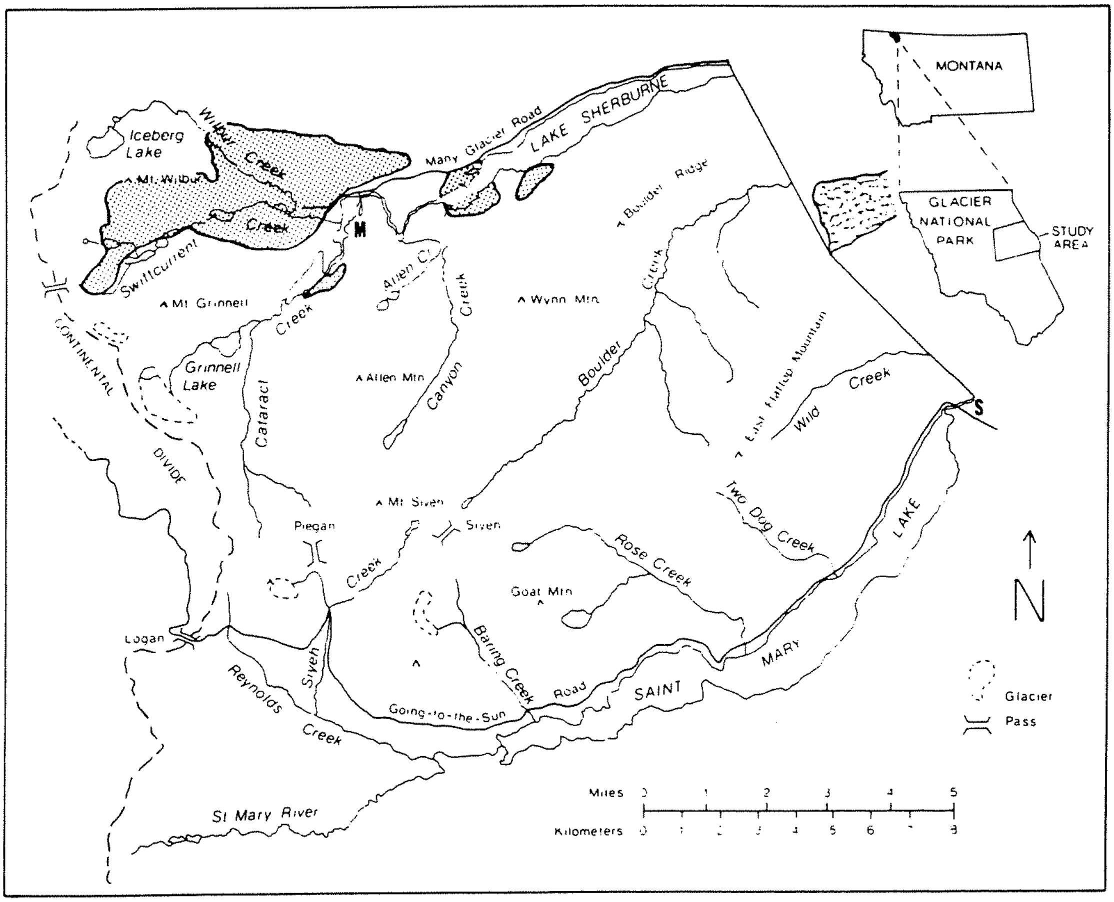


Figure 3. Specific study area for snow-avalanche terrain modeling. Dot pattern shows area of 1936 Swiftcurrent Valley fire which came from across the Continental Divide; stipled pattern shows the Napi Point fire of 1984 (fig. 5).

which form the park boundary. Snowsheds were built in 1910-1914 to protect the rail line from burial by avalanching; however, the burning of large areas of forest in and near avalanche starting zones (fig. 2) expanded the geographic extent of unstable snow so that avalanches cover broader swaths of railroad track than were originally covered with protective sheds (Butler and Malanson 1985).

For this study, we chose to examine a section of Glacier National Park east of the Continental Divide, which contains over 100 snow- avalanche paths and dozens of landslide deposits, and has been subjected to forest fires in 1936 and 1984 (fig. 3). The area chosen is one of the most heavily visited portions of the park, and has several roads and backcountry trails which allow access to field sites.

METHODS

Landslide locations (fig. 4), particularly with reference to landslides occurring in burned parts of the study area (fig. 5a, b), were mapped on the basis of aerial photointerpretation and fieldwork (Oelfke and Butler 1985). Landslide type and slope aspect have also been categorized for these deposits. No other data have yet been calculated for the landslide deposits in the study area. Preliminary examination of this mapping and categorization reveals that generally north-facing, and therefore moister, landslide deposits of the slump/earthflow variety would be most likely to be reactivated in case of forest fire. However, because this portion of the research is still continuing, we devote the remainder of the paper to the analysis of snow- avalanche path location.

Because avalanches tend to occur in spatially-distinct locations, we used a GIS to delineate path location and analyze the spatial characteristics of sites subject to avalanching. We wished to determine why snow-avalanche paths are located where they are in the study area, so that we could then develop a cartographic model which illustrates areas of highest probability for areas of new snow avalanching in the event of a forest fire removing the vegetational cover. It was therefore necessary to map the locations of all avalanche paths within the study area shown in figure 3.

Aerial photointerpretation and field reconnaissance confirmed the location of 121 snow-avalanche paths within the study area. Field work in 1987 and 1988 revealed that little change had occurred in the outer boundaries, or numbers, of avalanche paths since 1966 when aerial photography was acquired. Minor extension of the longitudinal boundaries of some paths occurred as the result of a major high-magnitude avalanche episode in February, 1979 (Butler and Malanson 1985; Butler 1986a).

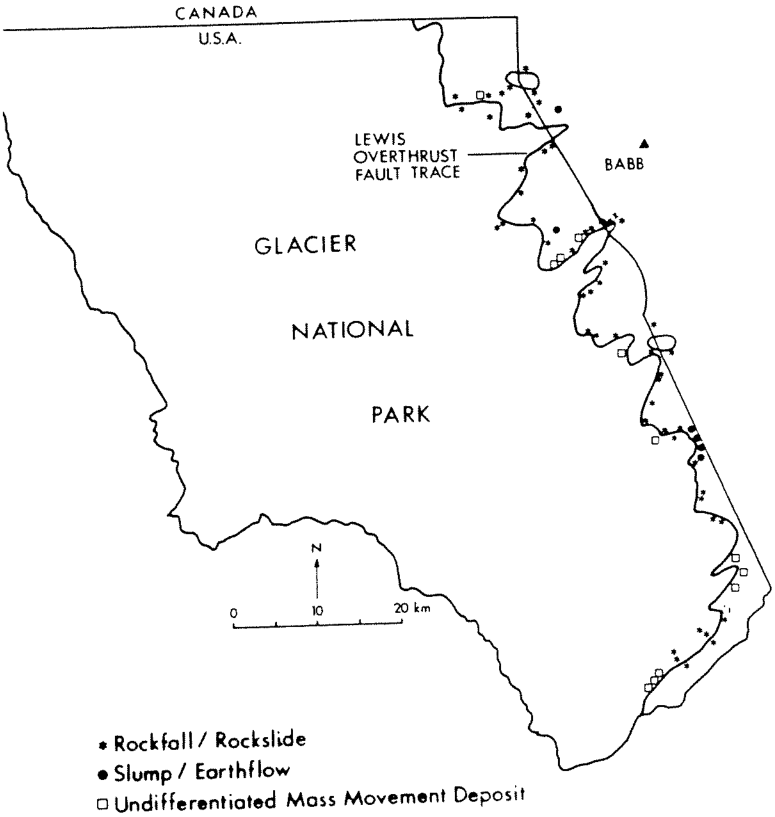


Figure 4. Landslide types and locations in eastern Glacier National Park. Compare to inset map, figure 3, for location of specific study area.

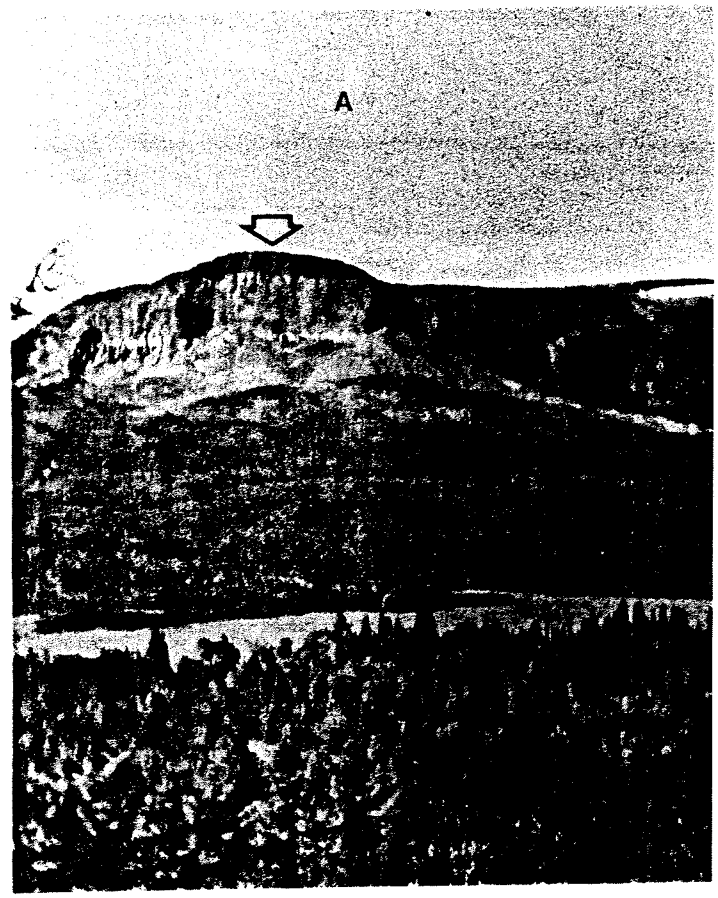
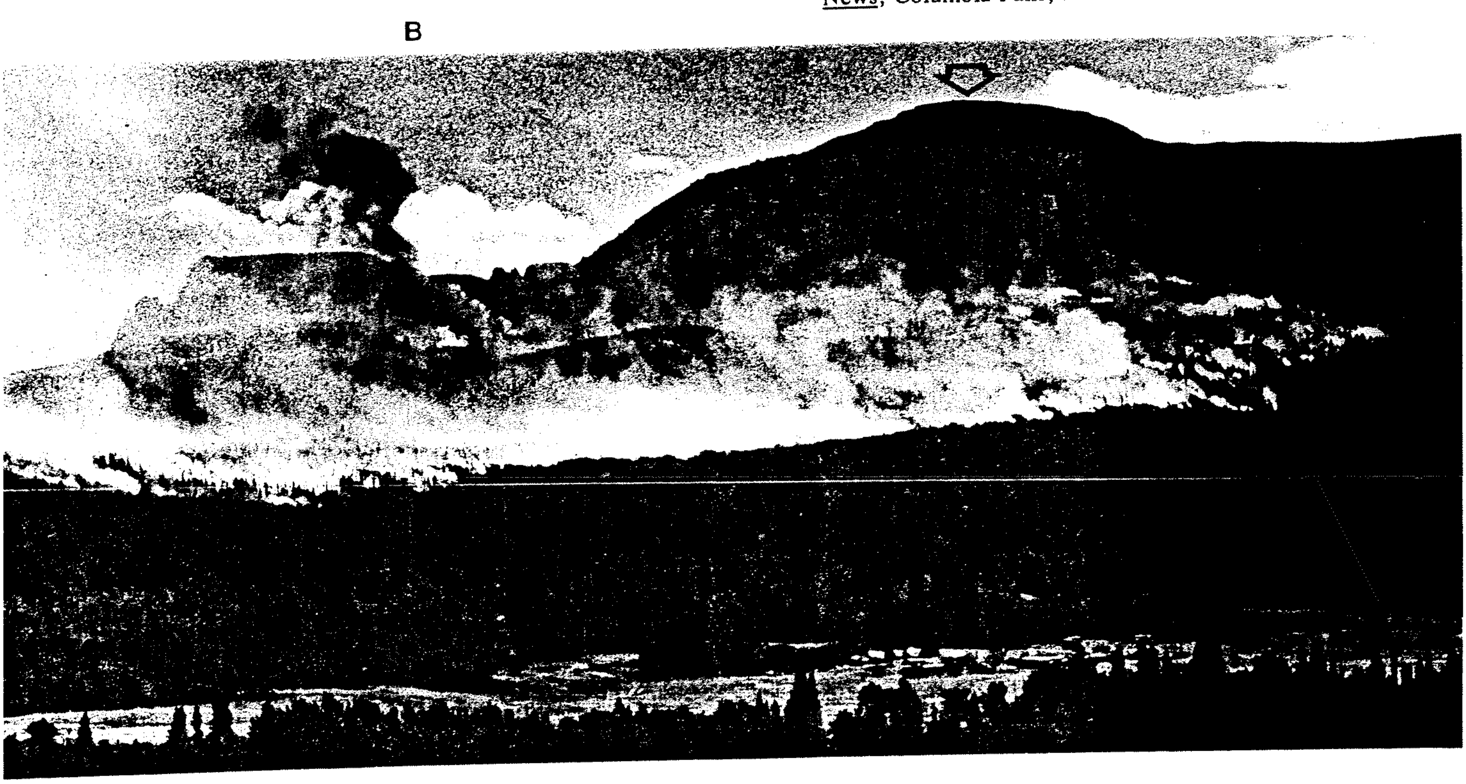


Figure 5. a. Napi Point (arrow), with rockfall avalanche and landslide deposits draping its north-facing base. Photo by D.R. Butler. b. Napi Point (arrow) fire of August, 1984, where forest fire burned and destabilized a broad area of landslide deposits. Photo by Brian Kennedy, Hungry Horse News, Columbia Falls, MT.



The location and areal extent of each snow-avalanche path were plotted on 1:24,000-scale topographic maps. Morphometric data were collected for each path from the topographic maps, aerial photographs, and field observations. The morphometric variables were entered into an INFO table within the ARC/INFO GIS for defining the character of each path from a geographic and geomorphic perspective. A GIS thematic overlay of path location was produced and merged with overlays developed for hydrography, geologic structure, lithology, topographic orientation, and land- cover type. Details of the development of these overlays may be found in Walsh and others (1990).

Most of the GIS overlays were compiled by direct digitization and transformation of mapped information for precise co-registration with other thematic overlays. Land-cover type and structural lineaments, however, were characterized through the digital analysis of Landsat Thematic Mapper (TM) data (fig. 6). Terrain orientation was characterized by a U.S. Geological Survey digital elevation model of the study area (fig. 7).

The land-cover GIS overlay was produced through an unsupervised classification of a 6 August 1988 TM scene (see Walsh and others, 1989, for details). Ground control information for approximately one-half of the avalanche paths was acquired during the summers of 1987 and 1988 to aid in cluster-labeling of the land-cover classification. Field data from other avalanche paths within the park (Malanson and Butler 1984a, 1984b, 1986; Butler 1985) revealed broadly similar vegetational types with similar spectral signatures. Cover-type classes used for this study were water, snow and ice, bare rock, lodgepole pine (Pinus contorta) forest, spruce/fir forest (primarily Picea engelmannii and Abies lasiocarpa), mixed herbaceous, and mixed shrubs.

Figure 6. Landsat TM principal components image of study area, with darker shades representing coniferous forest, lakes are black, alpine tundra is grey, and light tones representing fire successional lodgepole pine in Swiftcurrent Valley, and herbaceous plants and shrubs on avalanche paths and landslide deposits.

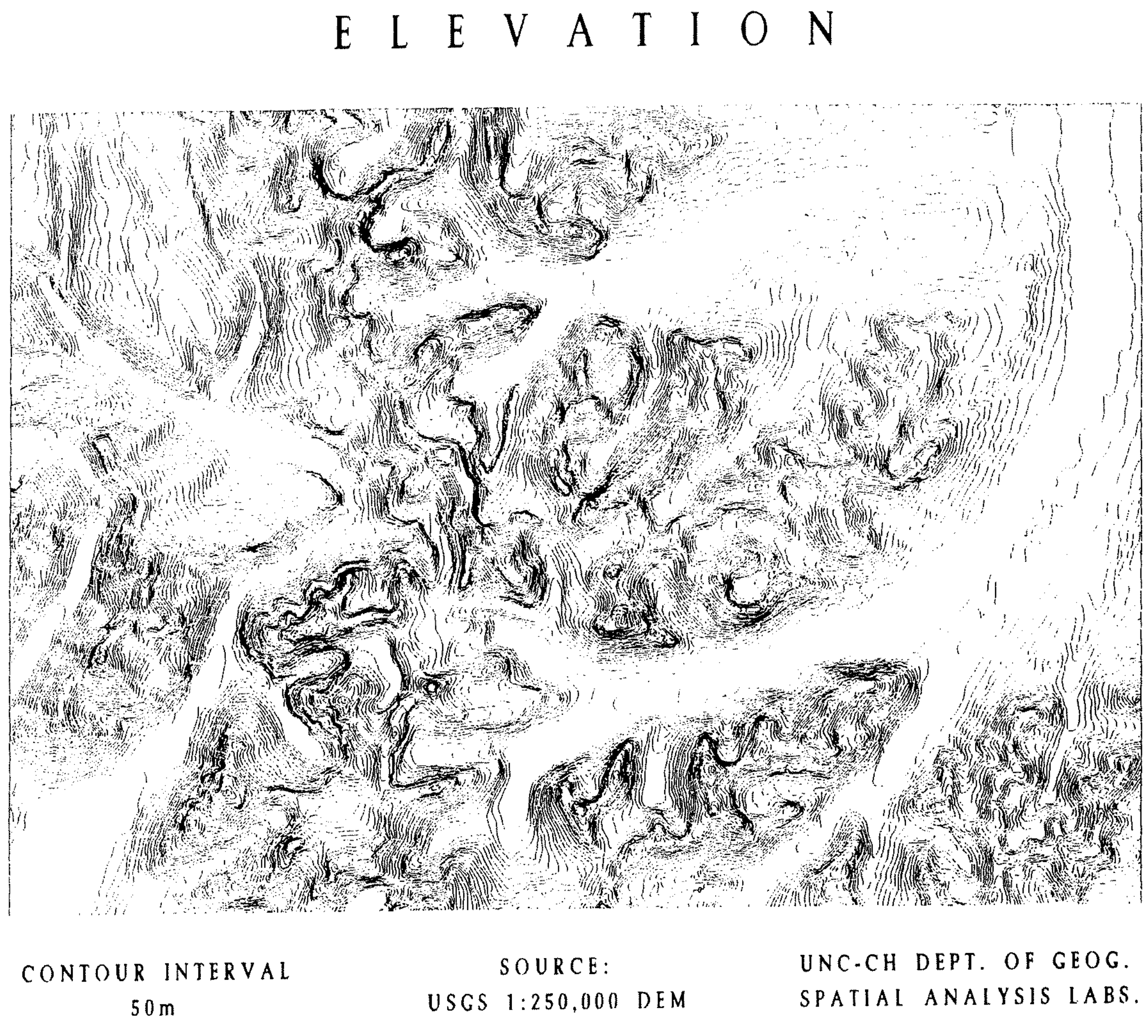


Figure 7. Digital elevation model of the study area.

Spatial proximity to geologic structural elements and hydrologic features (also controlled largely by structural elements) on the landscape was an important influence on the geographic distribution of snow-avalanche paths within the study area (Butler and Walsh 1990). Measurement of the distance of paths from sills, dikes, faults and lineaments, and rivers and streams was carried out within the ARC/INFO environment through the generation of buffers. Buffers are spatial zones of user-defined diameter that indicate distance from a specified target phenomenon. Distance measures of each path to the selected landscape feature were calculated and added to the path morphometric database. A separate thematic overlay of buffers surrounding sills, dikes, faults and lineaments, and rivers and streams was added to the GIS for integration with the other coverages (fig. 8).

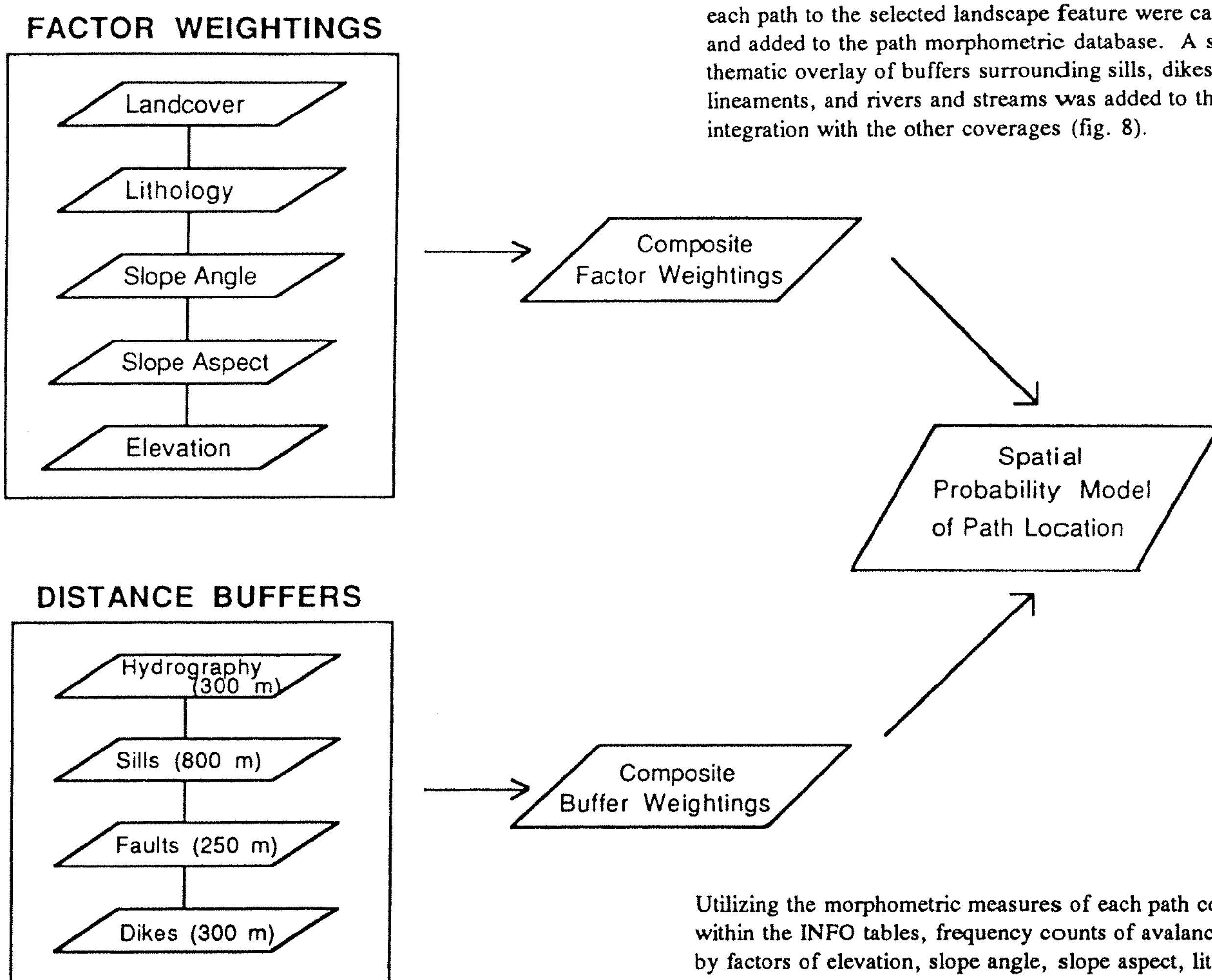


Figure 8. Schematic diagram of the units of the geographic information system used to model the spatial probability of snow avalanche paths in the study area.

Utilizing the morphometric measures of each path contained within the INFO tables, frequency counts of avalanche paths by factors of elevation, slope angle, slope aspect, lithology, and land cover were determined. The frequency data for each overlay were then normalized by weighted area measures (details of the weighting procedure may be found in Walsh and others 1990). Normalized frequency weightings also were derived for the proximal measures associated with spatial buffering. Buffers were weighted by the percent of all snow-avalanche paths occurring within the various buffer distances from the target feature.

RESULTS AND DISCUSSION

The end result of the GIS analysis, shown in figure 8, was a spatial probability map illustrating where, based on the factors and buffers analyzed, snow avalanches are most likely to develop in the event of removal of forest vegetation by a forest fire (fig. 9). When a forest fire occurs within the study area, the boundaries of the fire can be rapidly digitized and entered into the GIS, and merged with the spatial probability data displayed in figure 9. Forest fire extent and plant regeneration can be assessed through high spatial, spectral, and temporal resolution satellites, such as Landsat and SPOT. Walsh and others (1981) reported on the role of Landsat satellite data for delineating and assessing forest disturbances and levels of forest regeneration. Remotely sensed measures of plant productivity with time can be assessed through use of vegetation indices and merged into the GIS as distinct multi-temporal landcover coverages.

Assessment of the information in the GIS follows. Did the fire burn an area that is likely to become more prone to snow avalanching? If the burned area coincides with terrain categorized as high probability, the answer is yes. Park managers can almost certainly expect currently-existing path margins to expand, as occurred in the southern portion of the park during the 1910-1919 period described earlier, and new paths will probably also develop in those areas marked on figure 9 as high probability areas. If the burned area coincides with the area of medium avalanche probability, expansion of areas of pre-existing avalanching may be likely, but it is questionable if new avalanche-prone areas will become established. Little concern for expansion of avalanching need be given if the fire occurred in the regions of low avalanche probability.

Temporal data could also be added into the GIS in order to examine the effects of time passed since a fire. For example, the portion of the study area burned in 1936 currently supports a successional lodgepole pine forest assemblage. This provides stability and anchorage for snow on the slopes, but during the first several years after the fire more unstable snow would have existed. High, medium, and low hazard likelihood categories could be added to the GIS based on time since fire: high hazard/spatial probability during the first year after fire; medium hazard/spatial probability during the early successional stages prior to conifer establishment (5-10 years in Glacier Park); and low hazard/spatial probability once the forest has reestablished itself and stabilizes the snowpack. However, once some areas are opened to snow avalanching, it is likely that avalanching will continue there and that succession to coniferous forest will be indefinitely retarded; the still-bare upper reaches of the burned and expanded avalanche paths along the southern margins of the park are mute testament to the disruptive longevity of fire in avalanche-prone terrain.

Figure 9. Composite probability of where new avalanche paths should develop in the event of removal of forest vegetation by a forest fire.

ACKNOWLEDGMENTS

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GIS APPLICATIONS IN FIRE MANAGEMENT AND RESEARCH

Jan W. van Wagtendonk[1]

Abstract—In 1985, Yosemite began using a geographic information system as a for tire management and research. The system has been used to compare historic fire incidence over a range of topography and vegetation types. Parkwide fuel inventories and prescribed burn units have also been depicted to predict fire behavior and effects. Research applications have included a lightning strike incidence analysis and a fire regime analysis hased on climate, vegetation, fuels, and topography. Current projects include developing a 1-hour-timelag fuel moisture theme by coupling the GIS with the BEHAVE fire behavior system to predict the behavior and spread of large fires.

When Yosemite National Park was established in 1890, the enabling legislation specified that all "timber, mineral deposits, natural curiosities or wonders in the area be preserved from injury and retained in their natural condition." Since then, the natural resources of the park have changed. Some of this change has resulted from past fire suppression policies which were intended lo preserve the timber from injury, but which have significantly altered vegelalion composition and have allowed fuels to accumulale.

In 1970, a program of prescribed burning was initiated to mitigate these conditions; and in 1972, lightning fires were allowed to burn in much of the park under a specific set of prescriptions (van Wagtendonk 1978). These programs were initiated based on the results of numerous research studies and extensive analyses of field data. To aid in theses analyses, a geographic information system (GIS) was installed in 1985 (van Wagtendonk and Graber 199 1).

In the past, resource information was scattered in files and publications, and on maps of varying scale and accuracy. The advent of relatively inexpensive microprocessors, high-resolution graphics, and large mass-storage devices has made lhe USC of computers for entering, storing, retrieving, and analyzing resource information a practical technology. Such a system is being used to help Park Service personnel make informed fire management decisions, monitor long-term fire effects, and research complex fire relationships.

Data used to develop the various data themes were obtained from several sources. Digital data for elevation, slope, and aspect were obtained from the U.S.G.S. Mapped data from the park were used for fire management zones, vegetation type, fuel model, and past fire occurrence. Lightning strike data were obtained from the Automated Lightning Detection System operated by the Bureau of Land Management al the Boise Interagency Fire Center. Digital satellite imagery was used to reline the vegetation data.

The park's vegetation and fuels data are being surveyed in the field. The systematic surveys now being conducted mark the beginning of long-term monitoring of park resources. They will provide baseline data that will be used to verify classifications of remotely sensed imagery.

The software currently in use is the Geographical Resources Analysis Support System (GRASS) developed and supported by the U.S. Army Corps of Engineers (Westervelt 1988). 11 is a raster-based system with vector and image analysis capability and employs the UNIX operating system. GRASS was selected because it is in the public domain and runs on a computer with an open architecture.

FIRE MANAGEMENT APPLICATIONS

The first use of the GIS was to evaluate the role fire has played in Yosemite's ecosystems (van Wagtendonk 1986). Fire has been an important factor in these systems for thousands of years and is of considerable scientific and political interest.

Fire records dating back to 1930 were reviewed and the point of ignition and areal extent of each lightning fire were digitized. These were than compared to information from the other themes. This analysis showed that fire occurrence and size varied significantly with vegetation type, elevation zone, topographic position, and drainage basin. Table 1 shows the distribution of lightning fires by vegetation type. West-facing slopes received 67 percent of the fires greater than 50 acres in size. In addition, fires were significantly smaller during the 12-year period before the prescribed natural fire management program was implemented in 1972 than during the following 12 years.

The GIS was also used to develop a fuel model map for the park. Fuel models are generalizations of actual fuel parameters and are used to predict fire behavior (Albini 1976). The vegetation and slope themes were combined with field surveys to assign a fuel model to each area of burnable vegetation.

The GIS depicts fire management zones which divide the park into units where different fire strategies are employed. These units include the routine suppression zone where all fires are put out regardless of origin, the conditional zone where

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Table I. Distribution of Lightning fires by vegetation type, Yosemite National Park, 1930-1983. The number of fires per million acres per year is shown in the last column.

Vegetation Type	Area of Park		Lightening Fires		
	Acres	%	Number	%	#/m/y
Chaparral Woodland	31,975	3.1	38	1.9	22.0
Lower Mixed Conifer	146,935	7.6	563	27.7	70.5
Upper Mixed Conifer	108,869	15.3	513	25.4	87.3
Red Fir	63,951	24.3	327	16.2	94.7
Lodgepole Pine	232,202	21.5	467	23.1	37.2
Subalpine	59,383	8.6	36	I.8	I1.2
Alpine	110,391	9.5	38	3.6	12.2
Miscellaneous	7,613	10.2	41	.3	14.6
Total	761,319	100.0	2,023	100.0	49.1

lightning fires are allowed to bum before and afler the fire season based under specific conditions, and the prescribed **natural fire** zone where lightning fires are allowed **to bum at** any time based on prescribed conditions. Thcsc zones were revise following the Greater Ycllowstone Area tires in 1988: buffers were established bctween adjacent lands managed for different objectives. The GIS made **this** easy.

There are prescribed bum units within the suppression and conditional zones. Park personnel set fires in thcsc units to meet specific management objectives. Maps of thcsc prescribed bum units are **also on the system and** arc linked to data bases **that** include information on previous burns and bum schedules. Prior to burning, GIS maps of each unit arc prepared to show topography, fuel models, and resources of special concern such as archwlogical sites or endangered species habitat. These maps are used to plan **bums** and to predict fire behavior and effects.

FIRE RESEARCH APPLICATIONS

A fire regime analysis based on climate, vegetation, fuels, and topography is underway. Climatic data have been collected at a network of weather stations, and climate themes arc being created by extrapolating these data to the rest of the park by means of topographic variablcs, temperature lapse rates, and solar radiation equations. These themes, in conjunction with fire incidence, are being used to develop relationships with fire regime parameters such as fire frequency, intensity, and size.

Data on lightning strikes have been analyzed to detect spatial patterns and predict fire occurrence. Lightning strikes were significantly correlated with elevation but not by slope and aspect. Since vegetation is strongly related with elevation, vegetation also showed a significant effect on lightning strike **occurrence** (table 2). Although the vegetation types in Table 2 arc slightly different than those in Table 1, a comparison

Table 2. Percent of area and number of Lightning strikes by vegetation type, Yosemite National Park, 1985-1989.

Vegetation	%	1985	1986	1987	1988	1989	Total
Chaparral	3.1	27	12	21	27	32	III
Ponderosa	7.6	73	25	49	67	77	291
White Fir	15.3	193	58	114	130	168	663
Red Fir	24.3	378	98	151	259	333	1219
Lodgepole	21.5	301	135	130	292	380	1238
Whitebark	8.6	123	59	71	115	183	551
Alpine	9.5	115	85	53	161	200	614
Barren	10.1	116	58	66	II7	182	539
Total	100.0	1326	530	655	1168	1555	5234

shows that the greater number of strikes in the lodgepole pine, subalpine, and alpine types did not result in a proportionaly larger number of fires. In those types burning and fuel conditions are not condusive to fire ignition and spread.

The locational accuracy of the strike detection system is reported to be approximately one mile (Krider and others 1980). Additional analyses will be performed in which the data will be adjusted to compensate for this error. The GIS will draw a circle with a l-mile radius around each strike and then select a random point within the circle.

The GIS' most important application in fire management and research will be the prediction of growth of large fires. Initial steps have been taken to develop a map of fuel moisture based on a given set of weather conditions along with topographic, vegetation, and fuel variables (Andrews 1986). Elevation is used to adjust temperature, while slope and aspect adjust for differences in solar radiation. Fuel model and vegetation type determine how much shading occurs. The GIS combined these five themes into over 14,000 unique categories. When these were linked to the SITE module in BEHAVE (Andrews 1986), a fuel moisture value for each category was calculated.

Once fuel moisture is determined, fire behavior predictions can be made by linking the GIS directly to a large fire growth simulator. Bevins and Andrews (1989) are currently working on such a simulator; it operates in GRASS and combines the effects of moisture, wind, and topography on fire behavior. Outputs from the simulator will be residence time, flame length, and rate of spread. These could be displayed as maps, as could the area burned by time increments.

Predictions of fire growth will be invaluable to the manager who has to make a decision about a fire today based on the fire's expected location a month from now. These decisions will be easier to make if information about predicted future fire behavior and effects is available. For instance, a decision to suppress a fire because of smoke problems could be avoided if information about fire spread, fuel accumulation, and smoke dispersal were available. This may be available when all of the various predictive models are fully developed and linked with a GIS that contains current resource information.

CONCLUSION

The GIS in Yosemite has already proven to be a useful tool in fire management and research. Fire operations have become more efficient, and the role fire plays in park ecosystems is better understood. Future applications in rea-time situations will increase the utility of this system. Such applications will include fire planning, suppression operations, and post-fire rehabilitation efforts. GIS technology promises to make increasingly accurate information more accessible to decision makers and researchers; thus make possible more effective protection of our park's valuable resources.

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FIREMAP

George L. Ball and D. Phillip Guertin[1]

Abstract—FIREMAP is a model for simulating surface fire spread through heterogeneous fuels and over non-uniform terrain. The model was constructed using PROMAP, a language which allows dynamic spatial models to be constructed using raster GIS data bases. The GIS system is used to construct the necessary input data of fuel types, moistures, slope, wind speed and wind direction. The model has been tested against a set of conditions under which specified fire perimeter shapes should h e expected. The results of the tests indicate that the fire shapes developed using data representing actual field conditions arc reasonable. A model such as FIREMAP has application for prescribed hums. evaluating fire effects, and fire in the wildland/urban interface.

INTRODUCTION

Predicting the spread of fire is equally important for the use of fire as a management tool as it is in fire suppression. The difficulty of predicting the direction and speed with which a fire will move is compounded when the fire is burning in a rugged terrain of mixed fuel types. The development of a usable model that could generate and display the possible path of a fire using data from an actual site in a simple and straight forward manner would be extremely beneficial.

The BEHAVE system (Andrews 1986) gave fire personnel a tool which could be used to calculate various fire characteristics based on the Rothermel equations (Rothermel 1973). BEHAVE allowed the fire behavior analyst to use a set of measured conditions pertaining to the fire area and predict the rate of spread of the fire as well as several other factors. The rate of spread is calculated for the maximum direction of spread which is usually determined by the slope of the terrain and the wind direction. Additionally, adjustments are available to give the rates of spread for the flanking and backing fires. It is impractical to try to calculate all possible directions and try to chart the fire over any distance for extended periods of time. As the fire perimeter becomes larger, changes in the variables start to increase so quickly in complex terrain that it becomes no longer possible to try to predict the entire fire perimeter.

Attempts to model fire spread using computers has been an ongoing project in many locations. In Australia, Green (1983) and Green and others (1983) have developed a model of fire spread for bush fires (grassland and shrub vegetation types). Although the model seems to provide a reasonable fire shape it has certain disadvantages. First, the use of an ignition template predetermines what fire shape will be generated (in this case an ellipse). Second, is the assumption that fire spread is by the shortest path from the ignition point. This ignores the fact that as the fire grows the influence of the ignition source diminishes to zero.

A computer program written by Eenigenburg (1987) provides a method for calculating the fire direction and rate of spread. It is only applicable on small plots and requires the use of pre-marked locations to gather data about the fire. This makes it impractical for use in most situations.

Cohen and others (1989) have created a computer based simulation of fire that is used to test the strategies of fire management by deploying simulated fire fighting equipment. Although they indicate that the environment they are using is derived from Yellowstone National Park, there is no indication as to how the fire characteristics are calculated and what algorithms are used to spread the fire. The use of this program is not to predict the spread of fire but the management of fire. Again, this program is not practical for use in fire spread prediction.

A model called FIREMAP was conceived as a method of predicting the spread of a surface fire through heterogeneous fuels and over non-uniform terrain by linking to a GIS data base (Vasconcelos 1988; Vasconcelos and others 1990). Vasconcelos used the Map Analysis Package (Tomlin, 1986) which is a GIS available on IBM PCs and clones. The FIREMAP model was applied to data collected during a fire in Ivins Canyon, located in the Spotted Mountains in east-central Arizona. The correspondence between the actual fire and the model was encouraging enough to pursue the further development of the model.

Although the model produced results that mimicked the actual fire, there was concern about the accuracy of the model due to the underlying algorithms employed by the MAP program. The basic premise of the Spread operator in the MAP GIS is to move uphill. Although this is a reasonable assumption for fire, it ignores the fact that fire spread is a result of local changes in the neighborhood of the flame front. What was needed was an algorithm that would display the same characteristics as an actual fire and still maintain the

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integration with the GIS data base. If such a model could be constructed it would have to be verified against some known fire shapes.

Three important papers concerning fire shape proved to be relevant to the FIREMAP problem. The papers by Peet (1967), Van Wagner (1969) and Anderson (1983) present a comparison of fire shapes under wind driven conditions. The wind speed ranged from low (2-4 miles per hour) up to moderate (12-15 miles per hour). The corresponding shapes range from ovoid to elongated ellipse. These shapes are the result of fitting mathematical shapes to approximate the actual observed fire shapes. A test of the FIREMAP model would be to run it using a set of conditions under which the shape of the fire would be predictable. The remainder of this paper will discuss the development of the second version of FIREMAP and give examples of the results of the tests against predicted fire shape.

PROMAP

The original FIREMAP model was hampered by the deficiencies of the GIS program that was used to implement it. An analysis of what would be required to use GIS data bases to model processes such as fire led Ball (1990a, 1990b) to author PROMAP. PROMAP is a simulation language based on raster GIS. It overcomes the limitations of traditional GIS programs by using real numbers and the algorithms used in the operators are designed for iterative operations. These are essential components in dynamic simulation. The basic premise of PROMAP is the principle of cellular automata (Wolfram 1984; Couclelis 1985, 1987; Gimblett 1989, Casti 1989; Ball 1990c).

Cellular automata theory is based on the premise that processes can be described by the influences of neighbors. In this case the neighbors are adjacent cells in the data base. PROMAP make use of this idea in the action of many of its operators. This allows the development of models that respond to neighborhood influences. The spread of fire is dependent on what it encounters in the environment as it moves across the landscape. By utilizing cellular automata theory, the spread of fire can be related to the progression of the flame front from one cell to the next. Therefore, what is required is an algorithm which incorporates the transitions from one cell to another into neighborhood effects.

The implementation of FIREMAP in the second version operates from what would normally be considered the neighboring cell. In this manner the algorithm can scan the surrounding area and determine if there is more than one potential direction from which fire might spread into the cell.

Every cell is considered to be homogeneous as to fuel type, slope and other variables. Consequently, the fire characteristics of each cell can be validly computed using Rothermel's approach (Rothermel, 1972; Andrews, 1986). Each cell, however, can have its own characteristics. The direction of maximum spread in one neighboring cell may be away from the cell the algorithm is currently occupying. Another neighbor may have a direction of maximum spread directly toward the current cell. In this case the fire would spread from the second cell because the fire will spread faster from it then from the first cell. In this manner the model accounts for the differences in neighborhoods as the fire progresses across the landscape.

Testing the Model

To test the function of FIREMAP we established a set of criteria which would allow us to predict the shape of a fire. This set of criteria describes what we call the Zero State Conditions. Under zero state, we assume that the area of the fire is uniform as to fuel, zero percent slope, zero wind, and all other factors held constant. Under these conditions a fire started as a point source would burn in a circular pattern as in figure 1.

If we relax the condition of zero wind and allow the fire to be wind driven, then the shape of the fire should begin to approximate the shapes predicted by Peet, Van Wagner, and Anderson. With a 4 mile per hour wind the shape of the fire created by the model is seen in figure 2. The shape is not as elliptical as the mathematical formulation because of the square grid cell on which the model is running. The overall shape, however does show the expected heading fire with reasonable flanking and backing fires. Figure 3 shows the result of a wind shift during the simulation.

In figure 4 the right half of the simulation has been made using random fuel moistures in the range of 0-20%. The overall shape of the simulation compared to the uniform moisture simulation shows a more realistic fire pattern.

The ability of the FIREMAP simulation to produce shapes corresponding to the expected mathematical shapes is encouraging. The next step will be to compare the simulation to actual fire shapes using controlled burns.

FUTURE IMPLICATIONS

The capabilities found in FIREMAP show the potential for the development of a complete fire management tool. Two areas can be used as examples of how spatial dynamic models of this type could be used for fire management.

Fire Effects

The capability of FIREMAP to produce a realistic simulation of surface fire spread can be extended to post-fire effects. Since the intermediate calculations of the fire equations provide information concerning fire characteristics, such as fire intensity, the spread map can be altered to depict a map of those characteristics. For example, using the map of fire intensity, a model can be generated that would show what percentage of certain type of vegetation would be killed (Kunzmann and others 1990). Once this type of information is available, the next step is to consider what vegetation changes will occur over time.

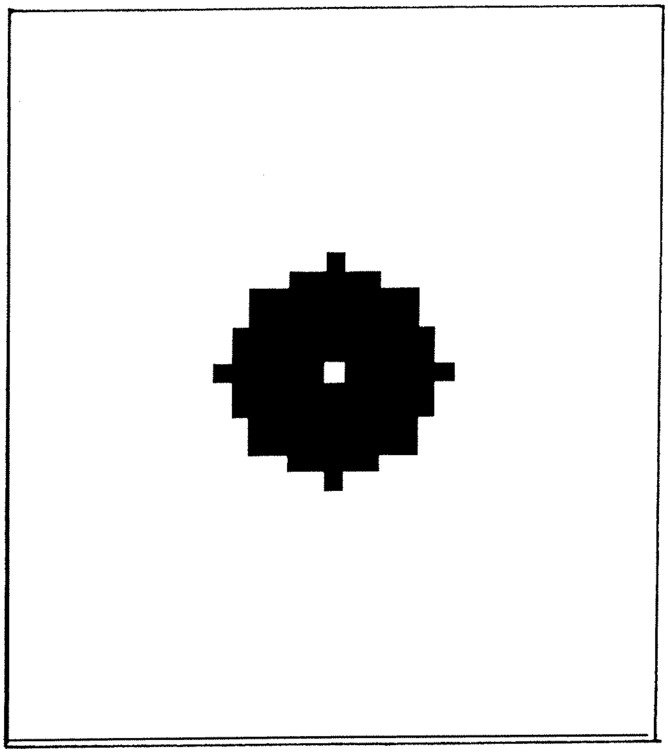

Figure 1--Fire spread simulation with zero wind speed. Unless otherwise noted, all simulations used a fuel model 9, 2% fuel moisture, 100% live woody moisture, zero slope, and wind direction of zero degrees. Duration of the burn is 400 minutes with cell sizes of 50 feet.

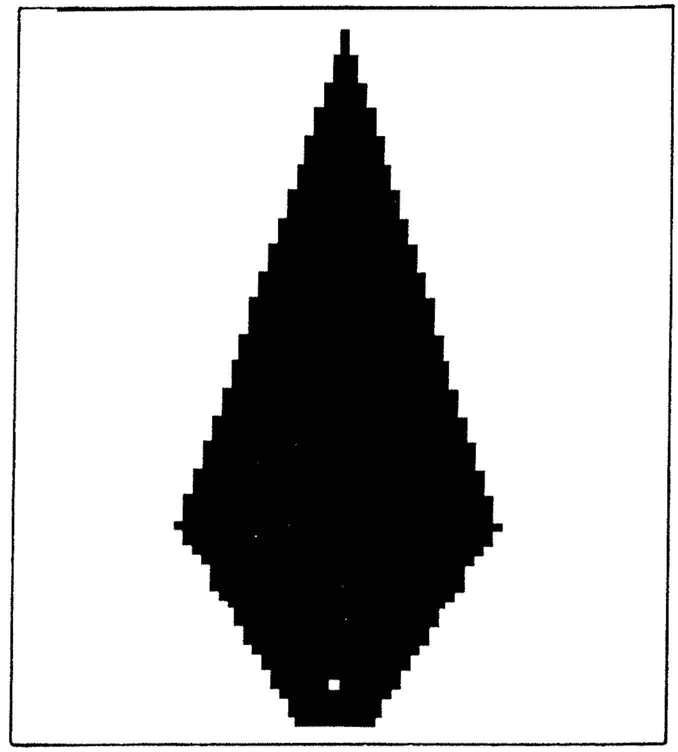

Figure ?--Fire spread simulation with a wind speed of 4 miles per hour. All other conditions arc the same as in figure 1.

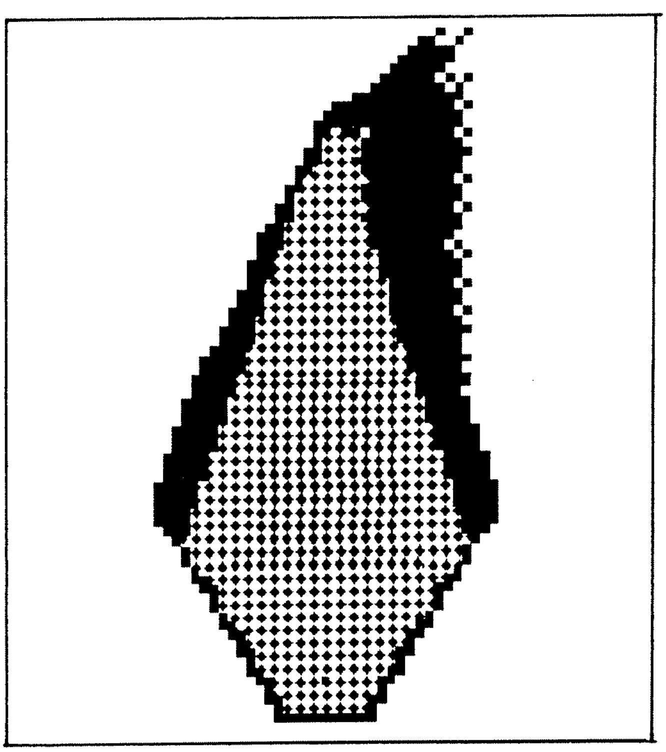

Figure 3--Fire spread simulation with a wind speed of 4 miles per hour. After 400 minutes the wind was shifted to 45 degrees for an additional 100 minutes. All other conditions arc the same as in figure 1.

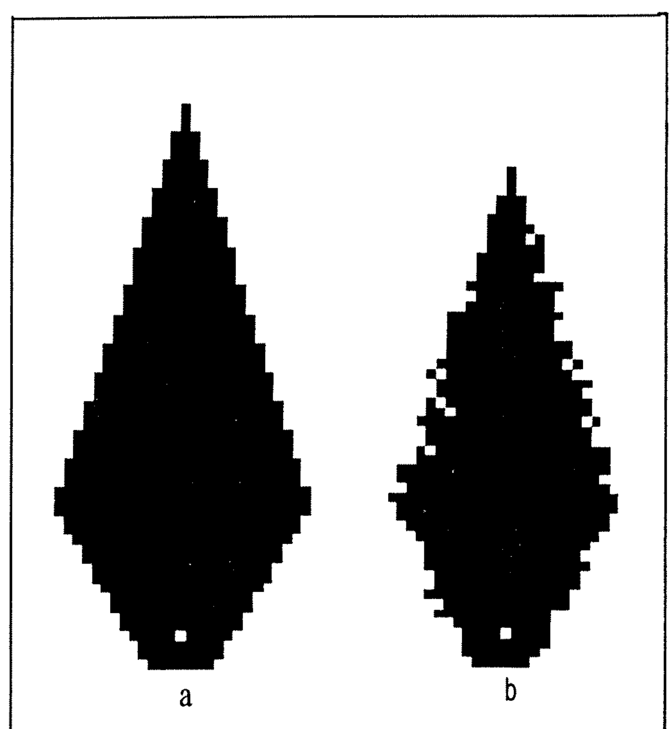

Figure 4--Fire spread simulation with 4 mile per hour wind for 480 minutes. The conditions for part a are the same as in figure 2. In part b the fuel moistures arc randomly distributed across the area with values from 0% to 20%. All other conditions are the same as in part a.

Risk Management

Even at the level of the current capabilities of FIREMAP, the application of this type of model to risk management is evident. The ability of the fire analyst to anticipate flame lengths, intensity and direction of spread of a fire would provide better utilization of effort and reduce the possible loss of life and property when managing fires.

In areas of the urban/rural interface, the use of FIREMAP could provide information on potential property loss of forest areas managed for fuel reduction versus areas that are not managed. This could have a significant effect on insurance rates and on gaining acceptance by the public for prescribed burn policies.

CONCLUSION

The ability of the FIREMAP model to simulate the spread of surface fire under specific conditions indicates that the use of this technology can provide better management tools. Further work will need to be done on improving the mathematical descriptions of fire for use in spatial dynamic models. As the models become more sophisticated and are verified by field tests, their application for fire management, fire ecology and related areas is readily apparent

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THE ART OF LONG-RANGE FIRE WEATHER FORECASTING

Francis M. Fujioka[1]

Abstract-On the heels of the Yellowstone fires of 1988, a Cabinet-level fire management review team recommended research "to improve the ability to predict severe tire behavior, conduct long-term weather forecasting, and identify past abnormal events." In a 1989 report, a Forest Service task force identified a high priority need for long-range weather forecasting, in support of prescribed fire management.

Research on long-range fire weather forecasting started in 1986 is described, particularly a newly developed system for forecasting fire weather elements in a monthly timeframe. Some fundamental differences between current and future forecasts are envisioned, not only in terms of content, but also in preparation and review. Both forecaster and user must come to grips with the quality of forecast information, which has implications for both long-range forecasting and long-range planning.

INTRODUCTION

The Yellowstone fires of 1988 have left scorch marks, not only among the Park's surviving trees, but also in the annals of United States fire management policy. The fire event was scrutinized at the highest level of federal government, when the Secretaries of Agriculture and Interior convened a fire management team to review national fire management policies and practices. Among the recommendations in the team's report[2] was the need for research "to improve the ability to predict severe fire behavior, conduct long-term weather forecasting, and identify past abnormal events."

On a separate but related issue, a Forest Service task force established to review prescribed fire management policy recommended in 1989 that high priority be given to research on long-range weather forecasting, to support prescribed natural fire management. Fire planners need to determine, as far ahead as reasonably possible, the buildup, duration, and termination of weather-induced fire potential. The assignment is hardly trivial; even in our most common experiences, each of us can probably recall an errant forecast, at that not even a long-range forecast.

Some reflection is warranted on expectations for long-range fire weather forecasts. This paper describes the goals, progress, and prospects of a program for long-range fit-c weather forecasting research, currently being conducted at the Pacific Southwest Research Station (PSW), in Riverside, California. The first section outlines the objectives of the research program, including a paradigm for the application of weather forecast information, irrespective of the forecast horizon (i.e., seasonal, extended-, medium-, or short-range). Research results obtained to date are then described. Finally, some conjectures are made on the nature of fire weather forecasts of the future.

FIRE WEATHER RESEARCH OBJECTIVES

The research on long-range fire weather forecasting at PSW was inspired by the information needs articulated by fire managers and fire scientists in 1985 (Rios, 1989). The group recognized that fire management planning required weather forecast information at lead times that varied from hours to months (Table 1). In this paper, seasonal refers to a 90-day forecast, extended-range to a 30-day forecast, medium to the 3-14 day range, and short-range to forecasts of less than 3 days. Strategic planning, therefore, requires seasonal and extended-range forecasts, preparedness planning requires medium-range forecasts, and implementation planning utilizes short-range forecasts. Particular effort was focused on the concept of a 30-day fire potential forecast for national level planning within the Boise Interagency Fire Center. Eventually, the Intelligence Section at BIFC developed a process for creating 30-day categorical forecasts of fire potential for the contiguous United States.

The purpose of the fire weather forecasting research at PSW is to develop fire weather forecast products identified (Table 1), but not generally available. In 1987, research was initiated to develop models for a monthly forecast of mean afternoon dry-bulb temperature, dewpoint temperature, windspeed, and precipitation frequency for the U.S. (precipitation frequency is defined as the number of days in the month that precipitation exceeds 0.1 inch). In 1988, research began on medium-range forecasts of the daily variations in these variables, over a period of (nominally) 10 days. In 1989, work commenced on the feasibility of forecasting seasonal fire climate, particularly in relation to El Nino and La Nina events (see Philander, 1989, for a good description of these events).

An equally important goal of the research program is to evaluate uncertainties in the forecasts. It is well-known that, by extending the forecast further into the future, the quality of the forecast can be seriously degraded. If the probabilistic character of the forecast uncertainties is described, the user can assess the risk inherent in using the forecast information in the decision process.

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[1]Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Riverside, CA.

[2]Report on Fire Management Policy, USDA/USDI, December 14, 198X. Unpublished report available at the USDA Forest Serv., Fire and Aviation Mgmt., Washington, D.C. 20090.

Table 1--The lead times for weather forecast information vary, depending on the management decision under consideration.

Decision	Strategic		Preparedness		Implementation	
	Seasonal. 4x/yr	30-15 days 2x/mo	14-6 days 2x/wk	5-3 days Daily	3-l days 2x/day	< 1 day 2x/day
Staffing and support (BIFC		X		X		
Severity fund requests	X	X				
National resource mgmt identify locate	X	X	X			
Alert			X			
Staging Level I			X	X		
Staging Level II					X	
Deployment					X	X

Using Forecast Uncertainty Information

In its report, the Forest Service Task Force on Prescribed Fire Management Criteria recommended a risk assessment procedure comparable to decision analysis[3]. Decision analysis provides a means of evaluating the merits of decision alternatives, weighted by information uncertainty (e.g., weather forecasts), and the values at risk (fig. 1). An example by Seaver and others (1983) shows how uncertainty information is used.

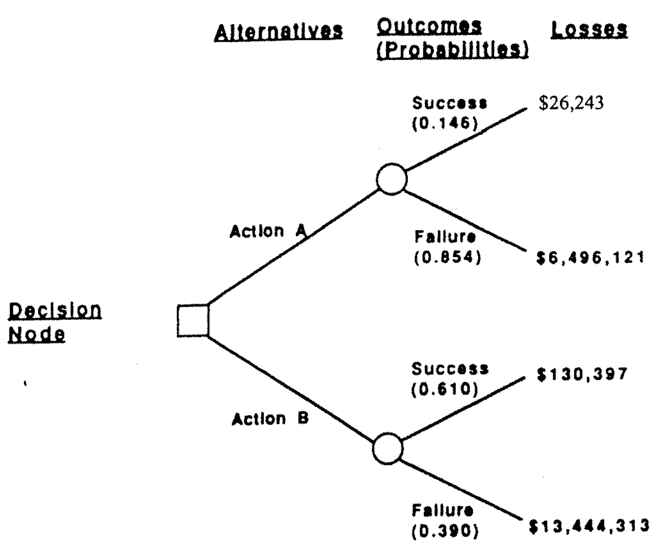

Figure l--Decision tree from Seaver and others (1983) illustrates how decision analysis integrates information on the uncertainties and the values of decisions and their outcomes.

In an escaped fire situation analysis, a fire manager considers whether to suppress a tire at (A) 7 hectares, or at (B) 40 hectares. The loss is much less at 7 hectares, but the probability of successfully implementing A is also small. The losses and probabilities can be depicted on a decision tree.

Suppose we decide, as a rule, to pursue that course of action which results in the smallest expected loss. The information in the decision tree can be used to calculate the expected loss for each decision:

Expected loss for A = probability of success of A * loss with success of A
+ probability of failure of A * loss with failure of A
= 0.146*$26,243+0.854*$6,496,121
= $5,551,519

Expected loss for B = probability of success of B * loss with success of B
+ probability of failure of B * loss with failure of B
=0.610*$130,397+0.390*$13,444,313
= $5,322,824

The above analysis suggests that the alternative to suppress at 40 hectares is optimal. Although a smaller loss would be incurred by implementing A successfully, the probabilities indicate that, in the long run, choosing A over B is more costly. Recently, Brown and Murphy (1988) demonstrated how decision analysis can be used to assess the economic value of weather forecasts in wildfire management. Their decision tree was more complicated than the one in the previous example, but the principle behind the analysis remains the same: consider the consequences of the decisions, and the probabilities of their outcomes, before deciding on an appropriate response.

[3]Report of the Task Force on Prescribed Fire Management Criteria, Forest Service, 1989. Unpublished report available at the USDA Forest Serv., Fire and Aviation Mgmt., Washington, D.C. 20090.

Effect of Uncertainties in the Probabilities

The preceding example assumed that the probabilities were known; the expected losses calculated in that context are true expected values. In reality, the probabilities can only be estimated, which introduces another level of uncertainty in the decision process. Suppose, therefore, that the probabilities are random variables, and that the values used in the computations are estimates. The resultant expected losses therefore are also random variables, subject to uncertainty. Where the calculated expectations in the preceding example were represented by points on the real line, the expected loss values calculated with the probability estimates are themselves only estimates. If the random variable representing the probability estimates can be described by a probability model, the calculated expected losses may be viewed in the context of confidence intervals. Hence, where the decision previously considered only which of the expected values was the larger, now the overlap, if any, of the confidence intervals might also be considered. In other words, the loss of certainty in the probability information clouds the expected loss calculations. If the smeared results (intervals) are still distinct from one another, the decision rule can be applied unambiguously. If, on the other hand, the intervals overlap, then the decision rule is compromised. The degree of overlap may be used as a basis for evaluating the acceptability of forecast uncertainties.

Presently, fire weather forecasts are not expressed in probabilities. Nor do they usually extend beyond a 5-day period. The research at PSW is aimed at providing the means to do both. The next generation of fire weather forecasts will extend the forecast horizon to 30 days.

EXTENDED-RANGE FIRE WEATHER FORECAST

The 30-day fire weather forecast was developed primarily in response to the national level strategic planning needs at the Boise Interagency Fire Center. The fire weather forecast will be integrated with information on crop moisture, the Palmer Drought Severity Index, and various fire danger and fire behavior indicators, to produce a forecast of 30-day fire potential for the continental U.S. The system that presently produces the fire potential map uses 30-day and 90-day predictions of temperature and precipitation from the National Weather Service (fig. 2).

The newly developed 30-day forecast models were tailored to fire weather needs (Klein and Whistler, 1989). They focus on mean afternoon conditions, when the fire weather threat is usually the greatest, and, they add the elements of relative humidity and windspeed. Specifically, the models predict the departures from the monthly afternoon (approximately 1300 Local Standard Time) means of the following variables:

- Dry-bulb temperature
- Dewpoint temperature
- Windspeed

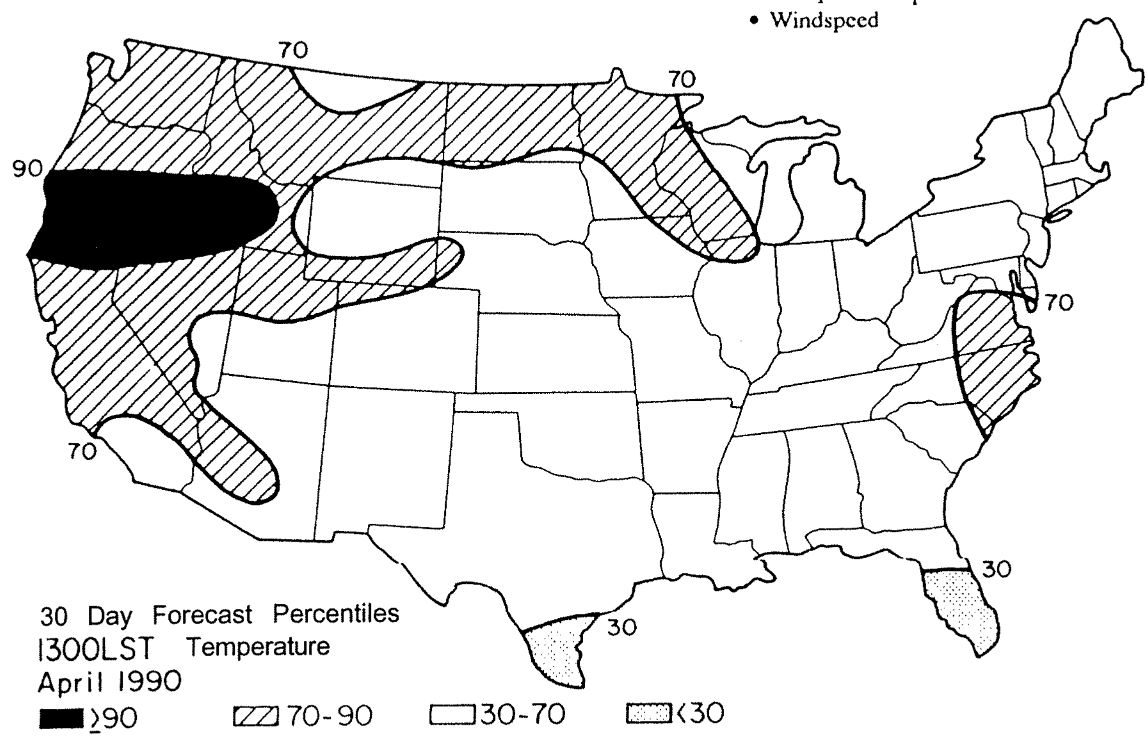

Figure 2--An extended-range forecast of the 30-day mean temperature percentiles for the contiguous U.S. The percentiles represent the proportion of the climatological database that the forcast value exceeds.

A model was also developed to predict the number of days in a month that precipitation would exceed 0.10 inch. This is complemented by existing National Weather Service models for monthly precipitation amount.

The models are driven by the forecast monthly mean pressure-heights at the 700 millibar level (nominally 10,000 ft), which is prepared by the National Weather Service twice monthly. The assumption underlying the models is that excursions of a variable from its monthly mean, as observed at a given location, are associated with large-scale atmospheric pressure patterns over the earth's surface; moreover, the excursions can be predicted statistically from information about the expected pressure-heights at a few points, and current conditions at the location of interest. In fact, the models are derived from regression analysis:

$$3\ (x,t+1) = a_o \Delta f(x,t) + \sum_{i=1}^{k_x} a_i \Delta p_i$$

in which $\widehat{\Delta f}(x,t+1)$ is the forecast surface weather anomaly for location x and month $t+1$, $\Delta f(x,t)$ is the observed surface weather anomaly for month t at location x, and $\{\Delta p_i\}$ are forecast 700 mb height anomalies at designated gridpoints for month $t+1$. The $\{a, \}$ are regression constants. The constant $a,$ may be 0, which then implies that current weather conditions at the location are not strongly correlated with next month's weather. Regression models have been developed for 127 stations across the contiguous U.S.

The forecasts are interpolated to an orthogonal grid, and contoured. The forecast at each station is also compared to the empirical distribution of the variable, and expressed as a percentage of the observed monthly means in the station record that the forecast value equals or exceeds. This transformation converts the forecast from its original units to a dimensionless number ranging from 0 to 100. Consequently, different variables may be forecast in different regions of the country, transformed to a percentage value by the process described above, and represented concurrently with other forecasts on a map. McCutchan and Main (1989) found that no single variable is best correlated with fire activity in the U.S., and that the forecast of different variables in different parts of the country might in fact be preferable.

LONG-RANGE FORECAST TOOLS OF THE FUTURE

Medium-range Fire Weather Forecasts

Research is presently focused on the development of medium-range fire weather forecasts, which implement computer models of global weather processes. Currently, the National Meteorological Center generates a daily medium-range forecast of weather conditions out to 10 days, but the distribution of this product is limited (Petersen and Stackpole, 1989). The forecast can describe daily variations of weather, which is the minimum temporal resolution required for National Fire-Danger Rating System (NFDRS) calculations.

Spatial resolution, however, is limiting, for local fire weather applications. The minimum grid interval is approximately 85 km, but the terrain model used to define the surface boundary removes terrain features of less than 5 degrees; the maximum height depicted in the Rocky Mountains is 2600 m. Therefore, the model cannot be expected to describe terrain-induced windflows that complicate fire behavior. Moreover, sea and lake breezes are not forecast accurately, thus reducing the ability to predict moisture variations in areas influenced by large water bodies. A typical way of enhancing the spatial resolution is through statistical models. For example, weather variations at fire weather stations can be modeled as a function of corresponding medium-range model output. Presently, however, the database for such studies are somewhat limited, particularly for the current version of the medium-range forecast model. An objective of the current PSW research effort is to develop forecasts of the daily variations in fire weather over a 10-day period.

Seasonal Fire Weather Forecasts

The objective of the seasonal fire weather forecast is to estimate the weather-induced fire potential in a 90-day timeframe. This forecast will be a prediction of the mean weather conditions over the 90-day time period that begins approximately from the day that the forecast is issued. Like the 30-day forecast, the seasonal forecast will key on variations in large-scale, slowly changing weather patterns.

The experience of the National Weather Service shows that 90-day forecasts of temperature are moderately skillful in winter and summer, but precipitation forecasts do not fare well (Wagner, 1989). The forecastibility of anomalous precipitation may be enhanced during periods that global circulation systems exhibit strong anomalies, e.g. the El Nino and Southern Oscillation events, which are characterized by unusually low sea-surface temperatures in the Pacific Ocean, and unusually strong negative pressure gradient between Tahiti and Darwin, Australia (Chu, 1989). But the question of forecastibility cannot be answered without considering the intended use of the forecast.

A study of the correlation between El Nino and fire activity (Simard and others, 1985) showed that fire activity tended to decrease in the Southeast during El Nino years, but no relationship was apparent in most of the other states in the contiguous U.S. The correlation in the southeastern states was attributed to anomalously high precipitation experienced by those states in El Nino years, which generally decreased fire potential.

SUMMARY

The not-too-distant future will see the addition of long-range fire weather forecast guidance to the tools of the fire manager. These will include a forecast of daily variations of fire weather out to 10 days (nominally), a forecast of the 30-day means of fire weather variables, and a seasonal forecast of the 90-day means of temperature and precipitation effects. Statistics of forecast reliability will also be provided, so that the manager can assess the credibility of the forecast information, which can vary over time, space, and with particular climatic conditions. Equally important to the decision process are the values at risk, which can be integrated with the forecast information in a decision analytic model. At best, the models can provide guidance; decisions must still be made by decisionmakers. The forecasting system visualized here will provide the user with the tools, the process, and the information necessary to deal with long-range fire weather forecasts and their uncertainties.

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CULTURAL

PRIVATE, NON-INDUSTRIAL FOREST OWNER'S PERCEPTIONS OF CONTROLLED BURNING INFLUENCING FOREST MANAGEMENT

D.W. McConnell II and S.B. Baldwin[1]

Abstract—Perceptions of controlled burning' by private, non- industrial forest (PNIF) owners provide insight into their forest management behavior. Detailed personal interviews of randomly selected forest owners in the Wiregrass region of Alabama were conducted to determine relationships between these perceptions, ownership objectives, and forest management activities. Over two-thirds of those interviewed felt controlled burning was a useful forest management practice on their land, although only 25.3 percent were presently using controlled burning. Both positive and negative perceptions of controlled burning are presented. Emphasis is made on the relationship of these perceptions to forest management behavior by PNIF owners and the subsequent importance to professional foresters who work with this public.

INTRODUCTION

There are numerous and conflicting perceptions of fire in the context of forest management. While professional foresters perceive tire as a useful tool in manipulating forest conditions, fire use by private, non-industrial forest (PNIF) owners likwise has an environmental and historic logic. Trained fire management personnel may at times criticize or question reasons given by these owners for burning; however, the act itself is a planned, deliberate application of knowledge to meet a determined goal. Forester's perceptions of PNIF owners may not encompass this knowledge and may therefore limit communication between the two groups. In order to improve communication and cooperative management efforts between foresters and PNIF owners, it is important to discover the perceptions that these individuals have of forest management activities -- in this case, the use of controlled burning.

What are PNIF owner's attitudes regarding fire as a forest management activity? How do they become aware of its utility? Where do they look for information and assistance in its application? What arc their reasons for using controlled burning on their lands? And can wc determine whether those owners with positive perceptions of controlled burning arc more active managers (that is, using more activities) than owners with negative perceptions of controlled burning?

With the advent of the professional forester and the growth of industrial forestry in the South, the practice of burning was seen as a major obstruction to implementing scientific forest management (Schiff 1962, Riebold 1971). Frequent burning by livestock owners, turpentiners, and other woods residents prevented foresters from applying their knowledge in forest management (Pyne 1981). To the contrary, foresters found they spent the majority of their time working to control woods fires. It is doubtful that foresters of the early 1900s in the South felt fire was a useful tool in forest management, primarily because of their lack of control over its application. John Shea undertook a "psycho-social" investigation of woods- burners in and around Bankhead National Forest in Alabama in the late 1930s, and generalized his findings to the conditions and behaviors of other fire users across the southcast (Shea 1940). Shea presented the typical southern woodsburner as backward, uncaring, and irresponsible. Perhaps the most significant conclusion drawn from his research was that: .m:l "Southern 'woods burning' is a human problem and should be tackled in a scientific and human way." (Shea 1940) The significance lies in the recognition of human behavior as the problem source and in the proposition that systematic investigation was needed to determine the nature of that behavior and to identify possible means to modify that behavior.

Historically, PNIF's have been considered under-managed resources, producing much less than their capacity of ecological, economic, and social benefits (Burger and Teer 1981, Dutrow 1986, Rogers and others 1988). A perceived lack of PNIF owner awareness and understanding of forest management technology concerns professional foresters (Sedjo and Ostermeier 1978) as a cause of under-management (Black 1983). These problems have justified research on forest management technology transfer based upon communication between professional foresters and PNIF owners. A better understanding of communication elements, patterns, and needs between professional foresters and PNIF owners could contribute to the effectiveness of forest management efforts by both groups.

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'The term "controlled burning" is used in this paper as it reflects PNIF owner's perceptions of what fire in the woods should bc, and was the term used by participants in this study. No difference is implied hy the author between the terms "prescribed burning" and "controlled burning"; rather, the terms tend to illustrate the differences in paradigms of professional foresters and PNIF owners, respectively.

Research on agricultural technology transfer has typically employed diffusion and adoption models, which provide theoretical generalizations about how technology information is communicated to landowners and how they decide to use new technologies (Rogers 1983). Muth and Hendee (1980) demonstrated that such models could also be useful in explaining the adoption of forest management technologies. Key elements in a diffusion model are an innovation, its adoption by individuals, and its diffusion through a social system over time as a result of communication. An innovation is an idea or object that is perceived as new; its adoption is affected by a variety of characteristics. An adoption decision is a five-step learning process. First, an individual becomes aware of the innovation; if his interest is aroused, the individual will then seek additional information about the innovation. As his knowledge accumulates, the individual evaluates the merits of the innovation relative to current or alternative conditions. In the fourth step, the individual conducts a trial or experiment with the innovation, from which he eventually decides to either adopt, reject, or continue to gather information concerning the innovation. Information about technological innovations is often disseminated by technical practitioners, change agents, professionals, and educators (McNaul 1972, Vickers 1974, Grunig 1980, Rogers 1983, Rogers and others 1988). The practicing professional forester who assists PNIF owners has a dual communication role: that of helping owners become aware of new forest management technologies as well as providing detailed information in later stages of the adoption process. A major goal of extension forestry programs is to provide information and education opportunities for the improvement of PNIF management (Gould 1975).

Adoption models suggest that practitioners who cultivate an understanding of their client audience, including that audience's technical knowledge and decision patterns, are more effective in educating landowners and changing their behavior (Rogers 1983). This is consistent with interpersonal communication models described in communication texts (Fazio and Gilbert 1981). The goal of this study was to help foresters understand PNIF owners and their use of controlled burning; more specific objectives are presented below.

STUDY OBJECTIVES

The problem addressed by this study was to identify how private, non-industrial forest owners become aware, gather information, and conduct evaluations and trials in determining whether to adopt a particular forest management activity. Specifically, the study was developed to: (1) assess the background experiences of Alabama PNIF owners with controlled burning; (2) identify patterns by which Alabama PNIF owners make decisions about undertaking controlled burning; (3) identify PNIF owner characteristics useful in delineating adopter categories as described by Rogers (1983); (4) identify the use and influence of information and assistance sources in stages of adoption and diffusion behavior.

STUDY AREA

This study was conducted in the eight southeastern counties of Alabama that comprise the majority of the Wiregrass region of the state. These counties cover approximately 3.72 million acres, of which 2.34 million acres are forested. In these eight counties there are approximately 20,310 PNIF owners of between 5 and 500 acres who control 44.5 percent of the area's forestland.

METHODOLOGY

A standardized interview instrument was designed and pre-tested to obtain: (1) information on PNIF ownership objectives; (2) information on PNIF forest management practices; (3) indications of owners' opinions on these practices; (4) indications of information sources used by owners; and (5) information on controlled burning use by PNIF owners.

The sampling procedure used was a stratified random sample of PNIF owners in the eight counties who owned more than 5 acres but less than 500 acres of forest land. The sample size for the study was calculated from the total population following Blalock (1982), resulting in a sample of 145 individuals. The sample was stratified across the region by the ratio of the number of owners in each county to the total for the study area, giving the number of interviews needed for each county. The number of interviews planned for each county was increased by an expansion factor of 1.86. This buffer eliminated the need for additional selection of names from county records in order to replace names of persons who were deceased, no longer owned land, declined interviews, or otherwise could not be contacted to schedule an interview. A random sample of names was drawn from county land records in the tax assessor's office of the respective county courthouses. Each name drawn was checked against the criteria of ownership (PNIF versus public or industrial) and size (greater than 5 but less than 500 acres). For the latter criterion, Alabama Forestry Commission records were used to determine that individuals did not own more than 500 acres of land in the county. In addition, individuals living outside the state of Alabama or at a distance greater than 60 miles from the boundary of the study area within the state were rejected from the sample. Appointments for interviews were made either through telephone contact or by locating individuals using rural post office routes. All interviews were conducted in person by the principle investigator. Interviews were primarily conducted in individuals' homes, although a number of interviews were arranged at businesses, restaurants, or in farm fields to accommodate participants' schedules.

A bound copy of the interview instrument was offered to each respondent so they might better follow the questions of the interviewer. The interviewer recorded all answers given by participants on his copy of the instrument. These answers included comments in open-ended questions as well as remarks made throughout any portion of the interview session. Completion of the survey instrument required an average of 23 minutes. Responses from the completed interview questionnaires were coded for analysis using the Statistical Package for the Social Sciences (SPSSx) (Nie and others 1983). Chi-square tests were used to determine whether statistically significant associations existed between groups within the sample. The lambda statistic was also used to determine whether independent variables associated with PNIF owners were of any use in predicting particular dependent variables of PNIF owners and their actions. Open-ended question responses were organized and coded using content analysis. A measure of PNIF owner attitudes toward forest management activities was determined through a Likert scale. The Likert method is based on the assumption that a scoring of the responses to items describing a particular variable provides a reasonably good measure of the respondent's attitude towards the variable (Babbie 1983). The use of the scale also prevents purposive response bias or manipulation in that the respondent does not know what variable is being measured. Factor analyses were performed on Likert scale statements to identify attitudinal themes of participants. Cronbach's alpha was used to determine the correlation and homogeneity of participant responses in order develop attitudinal rankings.

RESULTS

The private, non-industrial forest owners of between 5 and 500 acres of forestland in the Wiregrass Region of Alabama were predominantly male, resident owners of approximately 75 acres of forestland. Most of the non-resident owners (64.9 percent) lived within ten miles of their forestland. The majority of individuals lived on farms or in rural, non-farm locations. While the average age of these PNIF owners was between 55 and 60, the ages ranged from 29 to 99 years. One- third of the individuals had less than a high school education, another third had completed high school, and the remainder had junior college to graduate degrees. The occupations of study participants ranged from teachers, construction workers, and ministers to government employees, housewives, and barbers. Among those PNIF owners who were retired (35.9 percent), the majority had been businessmen or farmers.

Within the study area, 71.7 percent of PNIF owners felt controlled burning was a useful forest management activity on their land. These owners commented that controlled burning helped clear understory brush and trash trees, helped fire-proof their land, and kept the pines growing free. These individuals had ownerships that ranged from 25 to 500 acres and displayed a broad range of occupations and educational backgrounds. The primary ownership objectives of those individuals who perceived controlled burning as useful ranged from the production of income from the sale of timber or providing a homesite to their land providing a heritage for future generations or shelter for wildlife (Table 1). The remainder of the PNIF owners cited the following primary ownership objectives: land as a future investment (9.6 percent); family recreation area (6.7 percent); hunting area (5.8 percent); firewood production area (3.8 percent); to preserve natural beauty (1.9 percent); and other reasons (4.8 percent).

Table 1. Primary forest ownership objectives of PNIF owners in the Wiregrass Region of Alabama who perceive controlled burning as a useful forest management activity on their forestland (N=104).

Primary Objective	Frequency	Percentage
Income from sale of timber	22	21.2
Homesite	22	21.2
Heritage for future generations	15	14.4
Shelter for wildlife	11	10.6
Future investment	10	9.6
Family recreation	7	6.7
Hunting	6	5.8
Firewood production	4	3.8
Natural beauty	2	1.9
Other reasons	5	4.8
Total	104	100.0

The primary reasons given by the 38.3 percent of PNIF owners who felt that controlled burning was not a useful forest management activity on their forestland were that burning "Destroys small trees." or "Damages timber." (31.7 percent); "[It] runs-off wildlife, especially songbirds." (15.1 percent); and "Mine is hardwood forest, so it doesn't fit." (12.2 percent). Demographic characteristics indicated that these PNIF owners tended to have smaller individual ownerships, somewhat lower education levels, and were more often non-resident owners. However, none of these demographic characteristics were significantly different at the 0.10 level from those of persons who felt controlled burning was a useful forest management activity. Further, the lambda statistic indicates that these individual characteristics are of little value in predicting the controlled burning utility perception of PNIF owners in the Wiregrass region.

The primary ownership objectives of 41 PNIF owners who felt controlled burning was not a useful forest management activity on their land ranged from their land providing a homesite or a heritage for future generations to providing shelter for wildlife or an area for family recreation (Table 2). Other primary ownership objectives cited by this group were: land as a future investment (9.8 percent); to have an area to cut firewood (4.9 percent); to preserve natural beauty (2.4 percent); and other reasons (4.9 percent). No one in this group identified having an area to hunt as their primary ownership objective.

Table 2. Primary forest ownership objectives of PNIF owners in the Uiregrass Region of Alabama uho do not perceive controlled burning as a useful forest management activity on their forestland (N=41).

Primary Objective	Frequency	Percentage
Income from sale of timber	5	12.2
Heritage for future generations	7	17.1
Homesite	8	19.5
Shelter for wildlife	6	14.6
Future investment	4	9.8
Family recreation	6	14.6
Hunting	0	0.0
Firewood production	2	4.9
Natural beauty	1	2.4
Other reasons	2	4.9
Total	4	100.0

Of the 104 individuals interviewed who perceived controlled burning as a useful forest management activity on their land, 35 percent cited "personal experience or observation" as their initial source of awareness of controlled burning utility. These persons described having first observed controlled burning in some fortuitous manner, such as noticing smoke, following it to its source, and then observing the actions of the fire and the individuals tending it. A number of these owners recalled returning to the burn area at some later date, ranging from a few days or weeks to two or more years, and making personal assessments of the impacts of the burns. Almost twice as many study participants who stated that controlled burning was useful cited personal experience or observation as their initial awareness source compared to the number who cited either mass media (newspaper or magazine articles, primarily) or Alabama Forestry Commission personnel as their initial awareness source (Table 3).

Table 3. Sources of initial awareness of controlled burning utility cited by PNIF owners uho perceived controlled burning useful on their forestland in the Uiregrass Region of Alabama (N=119)[1].

Source	Frequency	Percentage
Personal experience or observation	35	29.4
Mass media	20	16.8
Alabama Forestry Commission	19	16.0
Friend or neighbor	12	10.1
Industry forester	11	9.2
Others (five sources)	22	18.5
Total	119	100.0

[1]N is greater than the 104 individuals uho perceived controlled burning useful because some owners could not confidently identify a single source of initial awareness of controlled burning utility.

Responses to Likert statements on controlled burning grouped study participants as having positive, neutral, or negative attitude scores concerning controlled burning. These attitude scores were developed independent of the questions regarding the perceived utility of controlled burning. Study participants with positive attitude scores toward controlled burning as a forest management activity tended to cite Alabama Forestry Commission foresters as their initial awareness source twice as often as owners with neutral to negative controlled burning attitude scores. Individuals with neutral attitude scores concerning controlled burning as a forest management practice tended to cite mass media or personal experience or observation as their initial awareness sources.

Private, non-industrial forest owners were asked whether they knew of any neighbor's or aquaintance's use of controlled burning in the management of their forrestland. This line of questioning was intended to investigate possible vicarious experiences with controlled burning through others' use of the practice. Almost half (47.5 percent) of all individuals interviewed stated that they were aware of controlled burning use by neighbors or aquaintances. Over 82 percent of this group of owners also perceived controlled burning as a useful forest management activity on their forestland. A generalization from this could be that owners using or predisposed toward a particular forest management practice, such as controlled burning, are more likely to be attuned to other's use of the same or similar activities.

Approximately two-thirds (65.8 percent) of those persons who were aware of controlled burning use by neighbors or aquaintances felt positively influenced by the controlled burning experiences of others (Table 4). This number was equivalent to 31 .0 percent of the total number of individuals interviewed. These persons commented that they saw burning as an effective means for "clearing understory brush", "eliminating trash trees", promoting "better food for deer and turkey", and "helping pine trees grow better"

Of those individuals aware of others' use of controlled burning, 26.3 percent felt negatively influenced by neighbors' or aquaintances' experiences with controlled burning. Eighty percent of these persons stated that they felt the iirc was too hot or damaging, or said that the fire had escaped, burning unintended areas or someone else's land.

Table 4. Private, non-industrial forest owner's stated direction of influence from neighbor's or aquaintance's use of controlled burning (N=69).

Influence	Frequency	Percentage
Positive	45	65.8
Neutral	6	7.9
Negative	18	26.3
Total	69	100.0

All study participants were asked to whom they would most likely go for information if they had specific questions about the use of controlled burning on their forestland. This question was asked regardless of the individual's perception of the utility of controlled burning. Alabama Forestry Commission foresters were cited significantly more often than any other controlled burning information source regardless of

Table 5. Controlled burning information sources identified by PNIF owners of the Alabama Uiregrass Region by attitudes of owners toward controlled burning (N=145).

Sources	Attitudes			
	Negative	Neutral	Positive	
AFC forester	30	29	20	79
	62.5	47.5	55.6	54.5
Industry forester	5	5	3	13
	10.4	8.2	8.3	9.0
Other'	13	27	13	53
	27.1	44.3	36.1	36.5
	48	61	36	145
	100.0	100.0	100.0	100.0

Chi-square: 3.451, d.f. = 4 Significant at alpha = 0.10
'Other: ASCS personnel, Cooperative Extension Agents, friends or fellow Landowners, and forestry consultants.

owner's attitudes of controlled burning (Table 5). Those PNIF owners with negative attitudes of controlled burning expressed a distrust of industry foresters as information sources for controlled burning and cited county Cooperative Extension Service agents three times as often as their preferred information source.

When landowners were asked to whom they would most likely go for information if they had a specific question on forest management, there was a slightly greater range of sources given (Table 6). Again, Alabama Forestry Commission foresters were the most frequently cited information source. There were no significant differences in the proportions of forest management information sources cited when compared with owner's attitudes of controlled burning.

Private, non-industrial forest owners in the Wircgrass Region of Alabama who perceived controlled burning as a useful forest management activity on their forestland conducted or contracted a variety of forest management activities (Table 7).

The crosstabulation indicates that PNIF owners were more likely to conduct the following forest management activities when they considered controlled burning useful than those who did not perceive it useful: planting trees, establishing wildlife food plots, selling timber, using herbicides, preparing a forest inventory, using a written contract to sell timber, and constructing a road on their forestland. Individual PNIF owners who perceived controlled burning useful undertook 35 percent more forest management activities than those owners who did not feel controlled burning was a useful forest management activity. While the Chi-square statistic indicates a significant relationship at the 0.10 level between perceived utility of controlled burning and the number forest management activities undertaken by PNIF owners, the number of crosstabulation cells with fewer than five cases is too large to accept Chi-square as a valid test. However, the lambda statistic indicates that knowledge of PNIF owner's perceptions of controlled burning is a significant factor in predicting their use of other forest management aclivitics.

Table 6. Forest management information sources identified by PNIF owners of the Alabama Uiregrass Region by attitudes of owners toward controlled burning (N=145).

Sources	Attitudes			
	Negative	Neutral	Positive	
AFC forester	21	21	10	52
	43.8	34.4	27.8	35.9
Industry forester	a	5	3	16
	16.7	8.2	8.3	11.0
Other'	19	35	23	77
	39.5	57.4	63.9	53.1
	48	61	36	145
	100.0	100.0	100.0	100.0

Chi-square: 6.255, d.f. = 4 Significant at alpha = 0.10

'Other: ASCS personnel, Cooperative Extension Agents, friends or fellow landowners, and forestry consultants.

Table 7. Forest management activities conducted by PNIF Owners in the Alabama Uiregrass region by perception of controlled burning as a useful forest management activity on their forestland (N=226).

Activity	Useful.	Not Useful	
Planting trees	33	6	39
	18.3	14	17.2
Wildlife plots	38	30.4	52
	21.1		23.0
			56
Selling timber	43.3	30.4	24.8
Herbicide applications	14	4	18
	7.8	8.7	8.0
Forest inventory	14	2	16
	7.8	4.4	7.1
Sales contract	26	4	30
	14.5	8.7	13.3
Road construction	13	2	15
	7.2	4.4	6.6
Total	180	46	226
	100.0	100.0	100.0

Chi-square: 4.7479', d.f. = 6 Significant at alpha = 0.10 Lambda: 0.2890

'The number of cells in the crosstabulation with expected frequencies of less than five is greater than 20 percent. This condition does not allow statistically valid Chi-square tests.

SUMMARY

While studies of fire impacts began in the early 1900s, there appears to have been a hesitancy to study man's behavior in using fire. This investigation indicates that a significant proportion of PNIF owners in the Wiregrass Region of Alabama see controlled burning as a useful forest management activity in meeting a variety of ownership objectives. Further, nearly one-third of the PNIF owners first become aware of controlled burning utility through some personal experience rather than any media transmitted message. Regardless of PNIF owner's attitudes and perceptions of controlled burning, the Alabama Forestry Commission is the most frequently cited formal information source of controlled burning. Those owners who perceive controlled burning as a useful forest **management tool** tend to be more active forest managers relative to those owners who do not feel controlled burning is useful.

CONCLUSIONS

Controlled burning is a very visible forest management activity whose impacts can be observed in a short time period relative to many other activities. It is also suited to use on a variety of size scales, which is important when considering the range of ownership sizes or individual stand sizes found on PNIF lands. State forestry agencies can utilize their standing as controlled burning information sources as an opening to promote other forest management activities by PNIF owners who use controlled burning. Neighboring forest owners could similarly be encouraged to undertake more forest management activities through observation of other's activities. Controlled burning can therefore serve professional foresters as a communication tool by promoting increased contacts with PNIF owners. Through a better understanding of adoption and diffusion behaviors of private, non-industrial forest owners, professional foresters can become more proactive in their forest management information and assistance efforts with this public. Controlled burning users can be developed as informal change agents and secondary information sources by state forestry agencies, thus utilizing interpersonal networks within PNIF owner publics. This diffusion network approach by professional foresters would increase the effective targetting of information desired by PNIF owners for their specific management objectives. A consequence of this would be that PNIF lands would produce more of their potential ecological, economic, and social benefits.

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SOCIAL IMPACT OF COMPUTERS IN URBAN FIRE FIGHTING

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Abstract—Computers are rapidly expanding into the urban fire safety area. This paper presents some social implications caused by the use of computers for fire safety databases, arson prediction programs, and fire simulation programs. In regards to the new technological advances this paper raises questions concerning the pros and cons of how computers are being used, who is responsible for the technology, who decides how the technology is used, how does the new technology affect insurance rates, how does it affect the builders and owners, and who is liable for personal damage indirectly caused by the new technology.

INTRODUCTION

With rapid advances in computers and software, new technology is being employed in the area of fire safety. This paper discusses the social impact of this new technology, addressing social issues such as how computers are being used, who is responsible for the technology, who decides how the technology is used, how does the new technology affect insurance rates, how does it affect the builders and owners, and who is liable for personal damage indirectly caused by the new technology.

Current Technology

The use of computers in the fight against urban fires has included diverse areas such as resource allocation, planning, dispatching, training, inventory management, etc. This paper concentrates on the implications of computer usage in three main areas; computer databases, models to predict arson, and models to predict fire movement contained in structures. Computer databases are being designed to provide the fire fighters with more information about the area in which the fire is contained; the models to predict arson are being developed to stop the loss of property and lives which occurs each year due to deliberate fires; the models to predict fire movement are being designed to help risk managers determine the safety level of their structures.

Computer Databases

Probably the widest application of computers to the fire safety field has been in the area of databases. The National Fire Information Retrieval System (NFIRS) has a database for hazardous materials (HAZMAT) which contains information like the chemical name, its flashpoint, upper and lower explosive points, water miscibility, etc. Another database maintained by the Insurance Services Office (ISO) contains details on commercial and public buildings throughout the country. The National Institute of Standards and Technology (NIST) Center for Fire Research (CFR) has developed a computerized card catalog (FIREDOC) containing localized information about buildings and materials which can be retrieved by local fire departments (Watts 1987).

In Leominster, Massachusetts, the fire department uses software entitled CAMEO to store information about the location and nature of hazardous materials in the industrial areas of the city. The database contains information such as the properties of the hazardous material, health hazards, first aid measures, protective clothing, etc. While approaching the scene, fire fighters can be informed about the material by the dispatcher (Bisol 1989).

In Phoenix, Arizona, the fire department has gone one step further. They work with a sophisticated Computer Aided Dispatch (CAD) and Mobile Digital Terminal (MDT) system to increase their ability to more efficiently respond to the needs of the public. The system supports over 1.4 million people in Phoenix, Glendale, and Tempe. Each emergency vehicle is equipped with a computer system which can communicate to the main computers at the fire station. MDT enables them to display emergency data on their screen as they rush to the scene of the incident, sometimes even helping them to find the exact location of the emergency (Sawyer 1984). The Phoenix Occupancy Activity Reporting System contains information from building inspections, providing them with information such as the owner, number of occupants (calling out elderly or handicapped persons), fire code violations, hazardous materials, floor plans, etc. which enables the arriving fire chief to better position the fire apparatus to contain the fire (Sawyer 1984).

With CAD and MDT, communications have improved tremendously; messages go more quickly. For example, when a fire box alarm was triggered, the dispatcher previously searched the fire box catalog manually to determine the street address and nearest fire station. With CAD, the computer system handles this operation at a much higher speed. Furthermore, in a major fire up to sixteen pieces of equipment need to be dispatched. Using radio communications this would take ninety-six messages to dispatch the equipment and put it back on line. With the new system, all communication is done by computer (Sawyer 1984). Dispatch operators can now keep up with the calls during peak periods. Equipment is being put to more efficient use. Record keeping and data collection for

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management reports has been automated freeing the individuals lo focus on other areas. The safety of the public and fire personnel has been improved due to increased knowledge of the structure and its contents (people and material). The overall success of the system is attrihuted to the fact that the development team members worked very closely with the fire fighters. The fire lighters' experience enabled the developers to better understand what was required of the system to help the fire fighter; continuous feedback has helped to constantly improve lhc system. Using the computer has become common place for the new generation of fire fighters in Phoenix (Sawyer 1984).

Arson Prediction Programs

Each year arson causes thousands of deaths and injuries nationwide as well as property loss in the billions of dollars (Cook 1985). Arson-prevention workers, backed by insurance agencies, city officials, and community organizations, have applied computer technology to the fight against arson and have found that they can reduce the losses. The idea behind the effort is that certain economic, structural, and demographic characteristics of a building and its neighborhood could he connected to arson rates. Generally, owners who have a building occupied by low income minority individuals, with long term leases, at very little rent, have a higher incidence rate of using arson as a means of clearing the building for renovation.

Arson prediction models were constructed so arson-prevention workers could use the results of the model to target specific buildings which arc at high risk for arson. By knowing where arson is most likely to occur, the arson-prevention workers can focus their efforts (fire marshal monitoring to tenant organizing) more cflicienlly on preventing arson in that area. The computer has enabled arson-prevention workers to do what they could not do before; "store and analyze the large data sets necessary to pinpoint the buildings most likely to bc torchcd" (Cook 1985). Using databases from various agencics, which arc available to the general public, the arson prevention workers are able to combine information about a particular building; this information is then used to determine the possibility this building will be victim to arson. Some problems were experienced due to the dissimilar manner in which the various organizations stored data in their database. For example, the fire department identified fires by addresses which were not always accurate; lhc housing departments used block and lot numbers.

In 1979, the Boston-based Urban Educational System Inc. developed a computer program to identify buildings that arc prone to arson. The variables used by the program include fire history, code violations, and tenant complaints. The program enabled the Attorney General at that time, Francis X. Bellotti, to prosecute arson-for-profit operations with unprecedented success. The program has helped the prosecution through better data collection of prior fire history, code violations, etc. (Anon 1979).

Using the work performed in Boston as a starting point, workers in arson prediction in New York City created a program called the Arson Risk Prediction Index (ARPI). APRI is mainly a formula which takes into account variables, and weights associated with those variables, to produce a probability that the building will be victim to arson in the next year. Variables include building type, building location, vacancy rate, fire history, serious code violations, number of apartments, owner history, etc. (Dillenbeck 1985). The computer program was not only employed to predict which buildings were at high risk to arson but the arson-prevention workers were also able to discover patterns among owners and problem buildings. This capability enables arson-prevention workers to discover building owners who make a practice of burning their buildings for profit.

The experience gained by the New York City arson-prevention workers has shown that although the program can help narrow the scope of building which are prone to arson, the model is not perfect. Many of the buildings which the program put at high risk did not bum. In fact, when the formula was applied city-wide only 40 percent of the buildings selected were burned. However, when the formula was modified for specific neighborhoods, it was accurate 80 percent of the time. Such results indicate that this information might bc best used to identify the buildings where minimal prevention methods, such as sending warning notices to the occupants, should be employed (Cook 1985).

Fire Simulation Programs

Before the use of computers, engineers approached fire safety risks by looking at the codes. Codes arc standards of practice developed by consensus among engineers and other tire experts. The codes were based on very little actual calculation of fire hazard; therefore, construction based on these codes could not be accurately evaluated as far as risk during a fire. Most observations of fire movement were done by investigating accidental fire or from experiments conducted by various organizations. Fire safety engineers in lhcse organizations ignited a lot of materials and watched how they burned. This was costly and time consuming especially when trying different configurations of material. In 1971 a group of scientists, observing that fire is rigidly bound by physical laws, concluded that fire is a rational physical phenomena which follows a logical system (Fitzgerald 1983). Based on this premise, fire safety engineers started to develop models to predict the spread of fire through a building.

There are three aspects to analyze during a fire; fire movement, smoke movement, and people movement. The goal of a computer simulation is lo analyze these movements to identify the acceptable time interval between when an occupant is aware of a tire and when the exits arc blocked because of fire or smoke, thus, providing a tool to "understand, evaluate, and describe the expected performance and reliability of the fire safety systems" (Fitzgerald 1987).

Fire simulations can be modelled either as zones or networks. Zone models work by dividing the structure into several zones, defined by room boundaries. "Advantages of zone models are that they provide fast, reasonably accurate, modular code that runs on a personal computer (PC), they are fairly simple to update and extend, and can be used by non-experts. The disadvantages are that the model is two-dimensional, only works with simple room geometries, and uses empirical knowledge, which introduces further limits on its applications" (Anon 1989).

There are two major advantages to providing fire simulation programs which run on PCs. First, most organizations can afford a PC; therefore, they will be more inclined to use the software. Second, PCs are portable and can go wherever the user needs to take it. For example, fire engineers could carry the computer around as they examine the structure and input information immediately. The PCs could be installed on fire trucks and tied into the main system so the fire chief can obtain information on the structure and run analyses of the spread of the fire.

A disadvantage to zone models is the use of empirical knowledge throughout the simulation. Input data to the program is generally provided by a fire engineer who has inspected the structure. These values are the only data used by the fire simulation program to produce the results. The assignment of these values are purely expert guesses based on common training given the fire engineers. A current problem is the inconsistency of the numbers produced by the fire safety engineers; unique buildings require unique judgement which varies from one person to another. The credibility of the numbers can be increased by providing the analysts with a "decision support system" or "engineering support system" which will help them produce the more consistent numbers for the input data. The challenge to creating these expert systems is programming the "judgement" of the engineers.

Fire safety engineers analyze fire movement by looking at the various input data; for example, room contents and barrier strengths, to determine when these factors come into play and how much they influence the outcome. A graphical, or neural, network of inputs (contents) and outcomes (fire propagation) could be produced. The next generation neural network-based fire simulation program will be able to learn how fire spreads by observing constructed fires and learning the properties of fire movement much like an experienced fire safety engineer.

SOCIAL IMPACT

Some scientists believe that true answers to scientific problems lie in an analytical equation; numeric answers are only approximations. Today computer simulations are dealing with problems with so many variables that the "true visualization requires a numerical solution; the analytical equation is only an approximation" (Koshland, 1985). The fire simulation programs take into account so many variables (i.e. room fuel, barrier strength, etc.), and there are many it does not take into account (i.e. explosions, wind directions, etc.) that the model may be entirely different from the actual outcome. The arson prediction program has shown that arson patterns cannot be truly summarized in a mathematical formula.

"When decisions are based on the results of computer models, it is extremely important that we can trust the model's hardware, software, and input data" (Perrolle 1987). All three technologies are negatively affected by bad input data. In the fire simulation program, all the values for the input data are provided by the fire engineers. Therefore, interpretation may be different among various fire engineers resulting in the same structure producing different results based on the input data. Additionally, these results may all be different from what actually happens when the structure is on fire due to the absence of a critical factor in the program. For example, the fire simulation model relies on the fire suppression systems (e.g. sprinklers) working perfectly; however, in reality, complex systems have a tendency to malfunction and break down. If the fire suppression systems fail in an actual fire, the results of the model are incorrect. In the arson prediction program, diverse databases resulted in information not being matched with the correct structure; therefore, the predictions for arson in that structure were incorrect. In the computer databases, mistakes can happen at many stages. The data collected may contain errors; the data may be entered incorrectly; the joining of diverse databases may be done incorrectly. All these factors can contribute to an erroneous database which could result in mishaps at the scene of the fire. Another factor impacting portable computers, such as those used by fire fighters in Phoenix, is the failure of the hardware. On site, equipment will be exposed to excessive heat, smoke, water, and chemicals. Equipment failure in these harsh conditions must be prevented. Back at the station, down-time on the mainframe should be minimized since it would impact the flow of information to the on-site fire fighters.

All these factors contribute to the possibility that the programs can be very inaccurate or the systems can fail at critical times. When the new technology does not perform as expected the public, builders, occupants, fire fighters, insurance agencies, etc. are all affected. The following sections describe effects that computer technology has had on these groups of individuals.

The Public

As society's structures become larger and more complex the fear of an extensive fire where massive human lives are lost causes the public to develop what Perrow called dread risk. "Dread risk is associated with

- lack of control over the activity,
- fatal consequences if there were a mishap of some sort,

- high catastrophic potential,
- sanctions of dread,
- inequitable distribution of risks and benefits, and
- the belief that risks are increasing and not easily reducible" (Perrow 1984).

People perish in buildings year after year because of combustible materials used in construction and furnishings. Incidents occur weekly which show that the current codes are inadequate. The public, spurred on by such incidents as the MGM Grand Hotel fire on 21 November 1980 which killed 84 people and injured 679, wants to be better protected from accidental and deliberate fires, especially in high-rise buildings, nursing homes, and hospitals.

The public's concern have caused the introduction of stricter fire codes as well as the desire to test building designs for fire safety before construction starts. Now, the current problem has shifted into the other direction; the public trusts that the new technology will solve the problems caused by other modern conveniences, such as high-rises, condominiums, etc.

The public has come to depend on technology to provide a comfortable standard of living, yet the public does not consider the health, safety, and environmental consequences that accompany this new technology. Additionally, along with more accurate techniques for measuring risk comes increased public expectations for safety. The public expects that builders will implement all safety measures outlined by the engineers using the computer technology (Zuckerman 1989).

The fire prediction programs and other uses of computers in fire safety have increased the level of protection that the general public has in fires but has not yet eliminated the possibility of major fires and accidents.

Software Engineers

"Public awareness of the risks of modern technology spawned vast amounts of new regulations and laws helping to create a litigious society, a society in which juries are inclined to award large settlements to an individual no matter who is at fault" (Zuckerman 1989). A current issue being debated in the courts is "If the simulation is wrong, and because of this deaths and injuries occur, who is at fault; the developers, the people who supplied the input, the users?" Perrolle points out that "If computer software is considered 'goods' under the law, software suppliers could be held liable for damages caused by program errors" (Perrolle 1987).

If the company that produces or uses fire technology gets sued they will most likely discontinue development and use of these products. Many companies decide not to pursue ideas because of the threat of liability partly due to the lawyers who promote the idea that whenever there is an accident someone must pay. The technological advances in the fire fighting area have been, and will continue to be, slowed by the courts

Another issue concerns how much the company that produces these prediction programs should charge for the technology. In an ideal society everyone would have equal access to the programs, not just those who can afford them. Volunteer fire departments, which are funded entirely by local citizens, would not be able to afford the hardware and software costs to install these systems. However, if they were made available to the general public at a low cost, there is no means to prevent the malicious misuse of the technology.

Fire Safety Engineers

The intent of the fire safety engineers is to better protect the public caught in a fire and the fire fighters combatting the inferno. Armed with better analytical techniques, fire engineers can tell architects and designers how to create structures that will contain fires. If fire safety engineers are constantly coming up with new methods to contain fires and using the prediction programs to prove that building codes should be stricter, old buildings can never meet current code requirements. Additionally, the time required to change fire codes exceeds the rate at which new standards are being developed so fire codes cannot be kept up to date. Therefore, when a case appears before a judge, he must decide what code standards the case will be based on.

Additionally, the prediction programs are having a negative effect on the fire safety profession. Previously, the codes were set by consensus among the fire safety engineers. Now, by running the fire simulation program against structures which have recently burned, fire safety engineers can determine where better codes could have reduced the damage done by the fire. Therefore, the codes are being set by the results of the fire simulation program and not by the fire safety engineers. This may result in fire safety engineers viewing the simulation programs and expert systems as decreasing their status because this new technology is taking away their judgement.

The attitude of the fire safety engineers towards the new technology may severely impact the work being done in the expert system area. The new technology needs to be introduced into their profession as a set of tools to enhance their job not replace them. Even if the fire safety engineers accept the technology and assist in successfully completing the expert system work, the next generation of fire safety engineers must be careful to scrutinize the computer programs to catch mistakes; the fire safety engineers still need to be instructed in the older methods so they can make judgement calls in situations where the expert system cannot make a decision. A future problem facing fire safety engineers is the work load resulting from pressure to examine more and more structures. As more pressure is put on the fire engineers to examine more buildings, the chance that they overlook an important factor increases. However, the "decision or engineering support systems" will help to reduce the number of mistakes made during inspections.

Fire Fighters

Today, fire lighters are seeing the slow emergence of computers into their field. In Phoenix, the success of the new computer system can be directly related to the input supplied by the fire lighters during the design stage of the system. In a profession which is in dire needs of new recruits, members are hoping that the glamour of the computer technology and the promise of increased safety as a benefit of the technology will entice younger people to consider the profession. However, the new technology presents the fire fighters with other issues. The next generation fire fighter must not only understand the older methods but must also be computer literate causing problems finding qualified individuals. The younger fire lighters, dependent on the new computer system, need to still be taught the old system in case of system failure. The old techniques cannot be totally abandoned since lives may be threatened when the computer system is unavailable.

New issues concerning responsibility are being presented to the next generation of fire fighters. For instance, let's assume the building owner moves something into the building after the data for that structure was collected or the simulation program erroneously predicts the path of fire propagation. Both of these errors may cause the fire fighters to combat the fire differently which could result in fire burning out of control in a situation when it would normally be contained quickly. In incidents such as these, who is responsible for loss of life and property, the person who developed the computer system, the person who collected the input data, the person who entered the data, the fire chief who believed the output? Prior history has shown that the fire chief would most likely be blamed; in fact, the computer simulations might cause incidents of second guessing the fire chief's decisions by proving that if another step had been taken the fire would have been controlled. The fire fighters need to be aware that the technology is not flawless and they should not rely on it as their sole source of decision-making criteria. They need to find a balance between what their experience tells them and what the computer tells them to combat the fires.

Builders and Owners

Arson prediction models, and the databases used by them, are considered "an invasion of privacy" to most building owners. On the other hand, the occupants are glad to see measures taken to protect their homes. Since most owners are the ones who burn their buildings for profit, they feel their privacy is being invaded by this technology which enables insurance agencies, who do not want owners to collect money by burning their buildings, to track their prior history. Knowing they are being tracked may deter them from burning their own buildings.

Fire simulation models are beneficial in assessing designs and developing more flexible and cost effective fire safety practices. The United Kingdom's Safety and Reliability Directorate (SRD) uses the model routinely in safety assessments; the U.S. Coast Guard uses fire simulation models to improve ship designs in an effect to better protect their crews. Although, the program can be used to detect a serious problem at the design stage instead of the building stage, where it may be too late to make any changes, the strength lies in analyzing current buildings and making improvements to those buildings. By examining structures at the design stage, the fire simulation program enables one design to be compared to another to point out the weaknesses in the performance of some fire prevention systems. However, the program does not force the builder to implement the appropriate design. Most building owners, armed with the programs, can make decisions to determine whether they should risk lives (currently valued at $250K/person) during a fire or spend extra money at construction time to install better fire detection and suppression systems.

If the builders and owners decide to put in a better fire detection and suppression system, any additional money spent on these systems can, and probably will be, passed on to the public in higher costs, fees, and taxes. The builders and owners need to determine just how much the public is willing to spend to be better protected in buildings such as hospitals, schools, nursing homes, high-rises, etc.

Corporate Risk Managers

A corporate risk manager's job is to decide whether to buy insurance or protect the corporate risk through some other means. The corporation views the purchase of insurance as risk. Most companies don't have risk management; they handle it by buying 100 percent insurance. With the introduction of new technology, many companies wishing to decrease money spent on insurance will create new positions for the risk manager or make existing positions more prevalent.

By using decision trees, expert systems, databases, and prediction programs, the modern high-tech risk manager has the ability to determine how much is at risk in the corporation due to a fire. They can determine what they feel is acceptable risk and modify their existing buildings appropriately or purchase more insurance.

Insurance Agencies

Most insurance companies do not have technological engineers; they rely on history to provide them with the information necessary to determine rates. Faced with major losses due to structural fires, insurance agencies will bring computer technology into their office to help protect their interests. They are being forced to hire engineers on staff to inspect buildings being insured and set up computer systems which allow them to tap into the same information and databases used by the arson prediction program developers

Insurance agencies are faced with some tough ethical issues. The insurance agency is a business which must be profitable; therefore, most insurance companies will not insure a building which the programs state are either likely targets for arson or will have massive damage if started on fire. The insurance companies would probably even review older policies to determine if any should be cancelled for these same reasons. Furthermore, the technology will be used to justify higher insurance rates. The insurance company can simply point to the output of the program to "prove" the building is at high risk.

Armed with this new information and the compute power to process it, the insurance agencies can build a "Bad Building and Owner" database. This database could be used as basis to refuse insurance to the individuals who own buildings. If a building/owner is incorrectly placed on this list, measures need to be put in place to notify people when information about themselves or their building is in the database and how they can get incorrect information corrected.

CONCLUSION

This paper has focused on the social impact of the new technology being applied to fire safety engineering. At times the new technology seems to have more of a negative impact on society; however, there are cases were the new technology has saved lives. In Phoenix, the new computer system was received positively by all who used it and the result was more efficient response to the needs of the public. In New York City, the arson prediction program helped to decrease the amount of arson which took place in the Flatbush and Crown Heights communities. The U.S. Coast Guard has increased the safety of their crew by using fire simulation programs to improve the fire safety level of their ships.

The intentions of the developers of this new technology are rooted in helping the general public to be better protected from fires. As new technology appears, the developers and sellers must be careful to ensure that the systems are not blindly trusted or put to the use for which they were not intended.

Additionally, the public needs to made aware that technology is neutral; it's how technology is managed that cause problems. Therefore, it's not so much the information and output of the new technology but what is done with this information that is the potential problem.

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FIRE'S IMPORTANCE IN SOUTH CENTRAL U.S. FORESTS: DISTRIBUTION OF FIRE EVIDENCE

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Abstract—Evidence of past fire occurrence is estimated to occur on 22.4 million acres, or 26 percent, of the 87.2 million acres of forests in Alabama, Arkansas, southeast Louisiana, Mississippi, east Oklahoma, Tennessee, and east Texas. Data are drawn from a systematic survey of fire evidence conducted in conjunction with recent inventories of private and public forested areas in the South Central United States. Some 8.9 million acres that are estimated to contain evidence of fire are nonstocked or consist of sapling or seedling stands; X.2 million acres consist of sawtimber stands; and 5.3 million acres consist of poletimber stands. Fire evidence commonly occurs in forests of the Gulf Coastal Plain and the Ouachita Highlands--in areas dominated by pine and oak-pine forest types and by National Forest and forest industry ownership. Fire evidence is relatively rare in the Mississippi Alluvial Plain, the Boston Mountains of Arkansas, and most of Tennessee--areas dominated by bottomland or upland hardwood forest types and hy a mix of ownerships. Seventy-five percent of the acreage showing evidence of having burned during the past 10 years is associated with wood, livestock, or wildlife production, or with vegetation management; 3 percent is associated with a natural disturbance. No causal agent has been identified with fires occurring on 22 percent of the acreage.

Comparison with other estimates of annual average fire frequency by State and by potential causal agent suggests that fire frequency estimates based on evidence observations from forest surveys are credible. Given the widespread extent and distribution of fire evidence presented in this report, one implication is that any changes in fire regulations will have important consequences for forestry in this region. Because survey estimates are linked with location, forest stand, and tree characteristics, forest survey fire data should prove useful for exploring the relationship of past tire occurrence to regional air quality and wildfire danger. With the addition of measurements from a subsample of plots, forest survey fire data could be used to assess fire's impact on the production of water, livestock forage, wildlife habitat, and timber for multi-county and larger areas.

INTRODUCTION

Recurrent fire is essential to many pine forest ecosystems in the southern United States, but there have been few surveys of fire occurrence over broad geographic areas. State and federal fire control agencies use information about fire occurrence to estimate regional smoke hazard and to establish priorities for fire protection in forested areas. Forest resource analysts and others use such information to assess timber resource conditions and fire-use practices in selected areas. Fire also plays a role in livestock forage production, wildlife browse production, carbon storage, leaf litter biomass accumulation, and maintenance of water quality. Models of these multiple values therefore should include fire as a variable that influences the current and projected **status** of forest resources.

In the South, fire occurrence--whether planned or unplanned--is not uniformly documented. Wildfires occurring on Southern U.S. National Forest land are recorded by number, causal agent, and total acres affected (USDA Forest Service 1988a). For private and other public land under the protection of state forest fire control agencies, similar wildfire statistics are noted in a separate report (USDA Forest Service 1988b). State forest fire control agency wildfire records have been compiled Southwide by county for the periods 1956-1965 (Doolittle 1969) and 1966-1975 (Doolittle 1977). Wildfire records for areas not protected by fire control agencies are not available. Neither are there more recent compilations or more detailed wildfire statistics.

Information on the occurrence of prescribed (i.e. planned) fires across the South is scant. The use of tire as a vegetation management tool in southern pine stands has increased during the last 50 years (Williams 1985). Fire is used to prepare a site for stand regeneration, to dispose of logging slash, to reduce hardwood competition, and to limit wildfire hazards. For National Forest land, prescribed fire statistics are listed by total acres and management objective (USDA Forest Service 1988a). Comparable estimates for other public landholdings and private land areas are not available.

In some fire districts, local fire control personnel know only incidentally of owners with large landholdings where prescribed fire is **used**, as permission to burn is not required in all States. Many State agencies must rely on "ballpark" estimates gathered from these district personnel, from allied natural resource agencies, from cooperating forest industries, and from self-administered questionnaires completed by persons in districts that require burn permits. Annual

[1]Research Forester and Forester, respectively, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, 201 Lincoln Green, Starkville, MS 39759-0906.

statewide prescribed fire acreage estimates are compiled from these data sources (e.g. Ashley 1985, Miles 1985, Moody 1985). However, reliability of these estimates is uncertain (Wade 1985).

Since available fire occurrence data are incomplete at best and anecdotal at worst, they are difficult to compare at multi-county and multi-state levels of resolution. Regional distribution patterns and detailed fire occurrence data by stand-size class, forest type, and acres affected on nonindustrial private ownership are not reported and rarely are collected.

In this report, data about fire evidence and about related measures are presented and discussed. These data were collected during a systematic survey of fire evidence in South Central U.S. forests. Areas included in this survey were: Alabama, Arkansas, southeast Louisiana, Mississippi, east Oklahoma, Tennessee, and east Texas. Data on evidence of fire occurrence in the past decade are presented together with data on evidence of other activities in the past decade so that potential sources of fire, or causal agents, can be at least tentatively identified. These data, and the conclusions drawn from them, are examined for consistency with average annual fire occurrence information obtained from other sources.

METHODS

The Southern Forest Experiment Station's Forest Inventory and Analysis (FIA) Unit conducts an inventory sampling program that assesses the current status of and trends in private and public forest resources. Permanent 1-acre plots are located at the intersections of perpendicular grid lines spaced at 3-mile intervals throughout the South Central States. Detailed field observations are obtained in some 17,000 plots on land classified as forest (i.e., at least 1-acre in size, 120 feet in width, and capable of producing crops of industrial wood). When combined with ground-truth of photointerpretation for additional areas, observations from plot samples are expanded statistically to estimate all forest resources in a county, state, or region. Field observations are updated about every 8 to 10 years. Periodic analytical assessments and tabular summaries report the current status and trends in species, number of trees, forested area, and timber productivity. Data are reported by forest type, stand-size class, ownership class, and other characteristics. Further details, including definitions and criteria for classifying forest characteristics, are available in State Resource Bulletins (e.g., McWilliams and Lord 1988, Rudis 1988).

Evidence of past fire occurrence is recorded as present or absent, and consists of physical evidence of burn scars on trees and other objects, reduced litter depth, and other vegetational indicators. Fire evidence also is recorded by age class of the most recent occurrence. For the 1981 survey of Alabama, age class was defined as: recent (1 or 2 years), within 3 years, or 3 years or older. In subsequent surveys, categories have been fine-tuned to limit overlapping ages and establish an open-ended highest age category. The updated categories are recent (1 or 2 years), 3 years to previous survey, and older than previous survey.

Fire evidence observations have been recorded only once for the most recent surveys of each region: Alabama (AL) 1982, southeast Louisiana (LA) 1984[2], east Texas (TX) 1986, east Oklahoma (OK) 1986, Mississippi (MS) 1987, Arkansas (AR) 1988, and Tennessee (TN) 1989. Statistical inferences regarding differences in fire occurrence by forest characteristics are based on chi-square analysis of category frequencies, with significance of chi-square values established <u>a priori</u> at the 5-percent probability level.

Evidence of other activities originating since the previous survey are used to suggest whether fires were planned or unplanned. Timber production is recorded if evidence suggests such activity occurred since the last survey. These include timber management activities--site preparation and timber stand improvement-and timber harvest activities-clearcutting and partial cutting. Similarly, evidence of livestock use, game management, and nontimber cutting or clearing, and miscellaneous artifacts associated with human use, are noted as well. (Since age categories used in the 1982 survey did not specify age beyond 3 years, some of the evidence coded then may relate to fires that occurred prior to the previous survey. To avoid confounding by time period, detailed analysis of causal agents includes only data for surveys conducted after 1982.)

For the purposes of this report, fires are classified as "prescribed" where fire evidence occurs in conjunction with evidence of production (timber management or harvest activities, livestock use, game or nongame wildlife management) or miscellaneous activities associated with cutting or clearing (woody debris from noncommercial wood harvest, maintenance of right-of-way). Fires are classified as "wildfire" where fire evidence occurs together with evidence of natural disturbance or salvage operations. "Other agents" is applied to fires in plots with fire evidence and no evidence of production, miscellaneous activities, or wildfire. Detailed observation codes by category are available from the senior author upon request. These and other category and observation codes can be found in Forest Inventory and Analysis (FIA) field manuals (Quick 1980, FIA 1989)

[2]Budgetary constraints in 1983 limited the tally of fire evidence and nontimber activities. A statewide tally is planned for 1991 in Louisiana.

RESULTS

Firc evidence is cstimatcd lo occur on 22.4 million acres, or 26 pcrccnt of the 87.2 million acrcs of timbcrland surveycd. Firc evidcncc and survey year for each state arc as follows: Alabama, 1982, 7.1 million acres (33 pcrccnt of the timbcrland); Arkansas, 1988, 3.4 million acrcs (20 pcrccnt); southcast Louisiana, 1984, 0.8 million acrcs (43 percent); Mississippi, 1987, 4.8 million acrcs (28 pcrccnl); east Oklahoma, 1986, 2.1 million acres (43 percent); Tennessee, 1989, 1.7 million acres (13 pcrccnt); and cast Texas, 1986, 2.6 million acrcs (22 pcrccnt). For surveys conducted aftcr 1982, 73 pcrccnt of the evidence is associated with fires that occurred since each State was surveycd (approximatcly 10 years previously).

Estimates of fire evidence in forcstcd areas by county provide regional summaries within and among States (fig. 1). Counties with fire evidence in forests are concentrated chiefly in the Gulf Coastal Plain (south Alabama, Mississippi, and Texas) and the Ouachita Highlands (southcast Oklahoma and west central Arkansas). Fire evidence in forests is relatively rare in the Mississippi Alluvial Plain, the Boston Mountains of Arkansas, and most of Tennessee.

Forest Characteristics

Unless otherwise noted, all differences in fire evidence frequcncy by forest characteristics are significant, with chi-square values at probabilities less than 0.001.

Area estimates by forest type and stand-size class arc summarized in table 1. Forty percent of the 22.4 million acres estimatcd to have fire evidence is composed of nonstockcd, sapling, or seedling stands, 37 percent is composed of sawtimber stands, and 24 percent is composed of polctimbcr stands. Fire evidence occurs in all forest types. It occurs in 54 percent of pine plantations, 3.5 percent of natural pine stands, 30 pcrccnt of oak-pint stands, 20 percent of upland hardwood stands, and 6 pcrccnt of bottomland hardwood stands. Within stand size classcs fire evidence occurs in 3.5 pcrccnt of nonstockcd, sapling, or seedling stands, 22 percent of polctimbcr stands, and 22 percent of sawtimbcr stands. Percent of timberland area with fire evidence by forest type and stand-size class is shown in figurc 2.

In pine plantations, thc proportion of timberland arca with firc evidcncc is 57 percent in nonstocked, sapling, or seedling stands, and declines to 48 percent in sawtimbcr stands, a relatively small but significant difference. In natural pine stands, the proportion of area with fire cvidcncc, 35 percent, is not statistically significant by stand-size class. The majority of pine plantation area is in sapling-seedling stand-size class and thc majority of natural pine area is in sawtimber stand-size class. Results suggest that fire occurrence remains higher in pine plantations relative to other forest types throughout the life of thesc stands.

Fire evidcncc occurs more frequently in plantations than in natural pine stands, regardless of stand-size class. Fire evidence is less common in upland hardwoods and bottomland hardwoods than in pine stands. Fire evidence declines as stands mature.

Fire evidence occurs on 41 percent of forest industry land, 28 pcrccnt of public land, 19 pcrccnt of farmer-owned land, and 21 percent of nonindustrial private land (table 2). Forest acreage with fire evidence is concentrated in sapling-seedling stand-size class and in forest industry and public ownership. Public land with fire evidcncc is primarily in the sawtimber

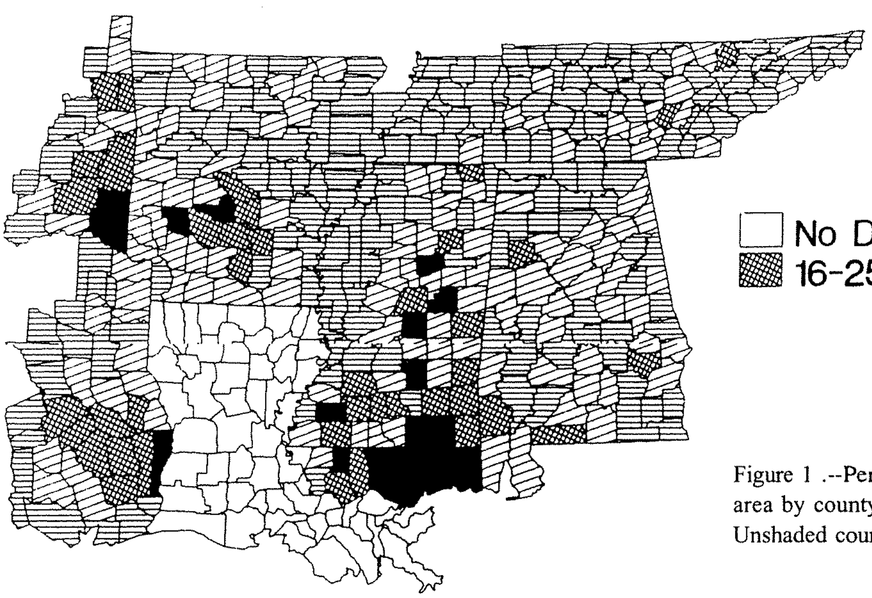

Figure 1 .--Percent timberland area with fire evidence per land area by county, South Central United States, 1982-1989. Unshaded counties arc scheduled lo be surveyed in 1991.

Table 1.--Timberland acres with and without fire evidence by forest type and stand-size class.”

Fire evidence and stand-size class	ALL types	Planted pine	Natural pine	Oak-pine	Upland hardwood”	Bottomland hardwood
	Million acres					
ALL stand sizes						
With fire evidence	22.43	3.57	6.00	4.83	7.25	0.75
No fire evidence	64.79	2.99	10.94	11.08	28.95	10.82
Total	87.22	6.56	16.94	15.92	34.22	11.57
Sapling-seedling”						
With fire evidence	8.92	1.98	1.03	2.42	3.25	.21
No fire evidence	16.45	1.49	2.00	3.27	8.14	1.58
Total	25.37	3.48	3.02	5.69	11.40	1.78
Poletimber						
With fire evidence	5.30	1.06	1.27	.91	1.88	.19
No fire evidence	19.16	.91	2.38	3.22	0.09	2.59
Total	24.48	1.96	3.64	4.13	1.96	2.78
Sawt imber						
Uith fire evidence	8.20	.53	3.70	1.49	2.12	.36
No fire evidence	29.16	.59	6.57	4.62	10.74	6.66
Total	37.37	1.12	10.27	6.11	12.86	7.01

[a] Rows and columns may not sum to totals due to rounding
[b] Includes 67,000 acres classified as nontyped.
[c] Includes 341,000 acres classified as nonstocked.

stand-six class and in natural pine and oak-pine forest types. Half of the forest industry land with fire evidence is in nonstocked, sapling, or seedling stand-six class. Forest industry land with fire evidence is relatively evenly distributed over planted pine, natural pine, oak-pine, and upland hardwood forest types. Farmer-owned land with fire evidence is evenly distributed by stand-size class; acres are primarily in upland hardwood forest type. Nonindustrial private land with fire evidence is evenly distributed by stand-six class; acres arc concentrated in upland hardwoods, natural pine, and oak-pint stands.

Location

If one is to correctly interpret regional patterns of fire occurrence in forested areas, one needs to consider the arrangement of forests and adjacent nonforest areas. The forested urban-wildland interface, i.e., the forested land adjacent to urban areas, is of considerable interest in fire science. Memphis, Houston, Little Rock, Mobile, and Birmingham represent the major urban centers in the South Central Slates survey area. However, the present sampling scheme is inadequate to categorize urban influences; few sampled plots occur in this area.

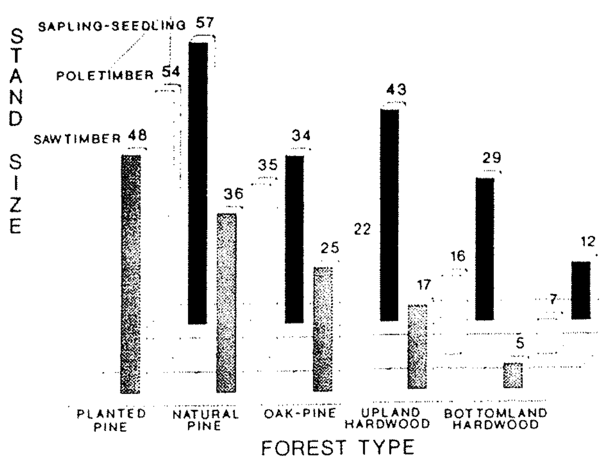

Figure 2.--Percent timberland area with fire evidence by forest type and stand-size class.

Table 2.--Forested acres with fire evidence by forest type, stand-size class, and ownership class[a]

Forest type and stand-size class[b]	All owners	Public land	Forest industry, incl. leased	Farmer	Other private
	Million acres				
All forest types					
Sapling-seedling	8.92	0.57	4.15	1.24	2.95
Poletimber	5.30	.49	1.74	.96	2.11
Sawtimber	8.20	1.51	2.00	1.50	3.19
Total	22.43	2.57	7.89	3.70	8.25
Planted pine					
Sapling-seedling	1.98	.07	1.58	.08	.25
Poletimber	1.06	.03	.82	.05	.16
Sawtimber	.53	.08	.21	.06	.17
Total	3.57	.18	2.61	.19	.58
Natural pine					
Sapling-seedling	1.03	.13	.32	.18	.40
Poletimber	1.27	.18	.47	.16	.45
Sawtimber	3.70	.86	1.09	.45	1.30
Total	6.00	1.18	1.88	.79	2.18
Oak-pine					
Sapling-seedling	2.42	.18	1.20	.25	.79
Poletimber	.91	.13	.21	.16	.42
Sawtimber	1.49	.31	.36	.29	.53
Total	4.83	.62	1.76	.71	1.74
Upland hardwood[c]					
Sapling-seedling	3.25	.18	1.00	.68	1.40
Poletimber	1.88	.14	.21	.53	1.01
Sawtimber	2.12	.23	.24	.60	1.05
Total	7.25	.54	1.44	1.82	3.46
Bottomland hardwood					
Sapling-seedling	.21	.01	.06	.04	.10
Poletimber	.19	.01	.04	.06	.07
Sawtimber	.36	.03	.10	.09	.14
Total	.75	.05	.20	.20	.31

[a] Rows and columns may not sum to totals due to rounding.
[b] Nonstocked areas (89,000 acres) are included in sapling-seedling stand-size class.
[c] Includes 26,000 acres classified as nontyped.

The largest non-forested areas in the South Central States include the extensive farmland acreage along floodplains of the Mississippi and Arkansas Rivers, the Blackbelt Prairie crescent that stretches from north central Mississippi to central Alabama, and the Central Basin of central Tennessee and north Alabama (fig. 3).

Areas dominated by southern pine forest types contain the largest concentration of forested plots with fire evidence. Clusters of plots with fire evidence, particularly those of relatively recent origin (triangles, fig. 3), indicate areas where fire has played an important regional role in forest ecosystem dynamics. Although detailed geostatistics are needed to verify the significance of spatial patterns, the density of forest industry landholdings and pine-dominated public timberland (Rosson and Doolittle 1987) appears directly related to the density of fire evidence.

Plots with evidence that fire occurred since the previous survey (triangles, fig. 3) are to be distinguished from plots with evidence of older fires (circles, fig. 3). A visual inspection of patterns suggests that, on average, areas with historical fire evidence also contain more recent fire evidence. A careful examination of patterns formed by plots with older fire evidence can suggest additional hypotheses. Geostatistical analysis, coupled with a geographic information system and knowledge of historical fire occurrences, should be helpful in further investigation of pattern differences.

Causal Agents

Approximately 314 of the acres with evidence of fire since the previous survey (excludes the 1982 Alabama survey) also contains evidence of activities associated with production of timber, wildlife, or livestock, or with miscellaneous forms of vegetation management. Known wildfires are noted on 3 percent of the acres. Fire evidence not clearly associated with a causal agent occurs on 22 percent of the acres (table 3). Figure 4 shows percentage of acres with fire evidence by causal agent and ownership class. Timber production dominates on forest industry land (81 percent), and animal production is highest on farmer-owned land (30 percent). Timber production dominates in sapling-seedling stands, and is high for both poletimber and sawtimber stand-size classes (fig. 5). It is notable that the percentage of sapling-seedling acres in the "other" causal agents category is significantly smaller than the percentages of poletimber or sawtimber acres in that category.

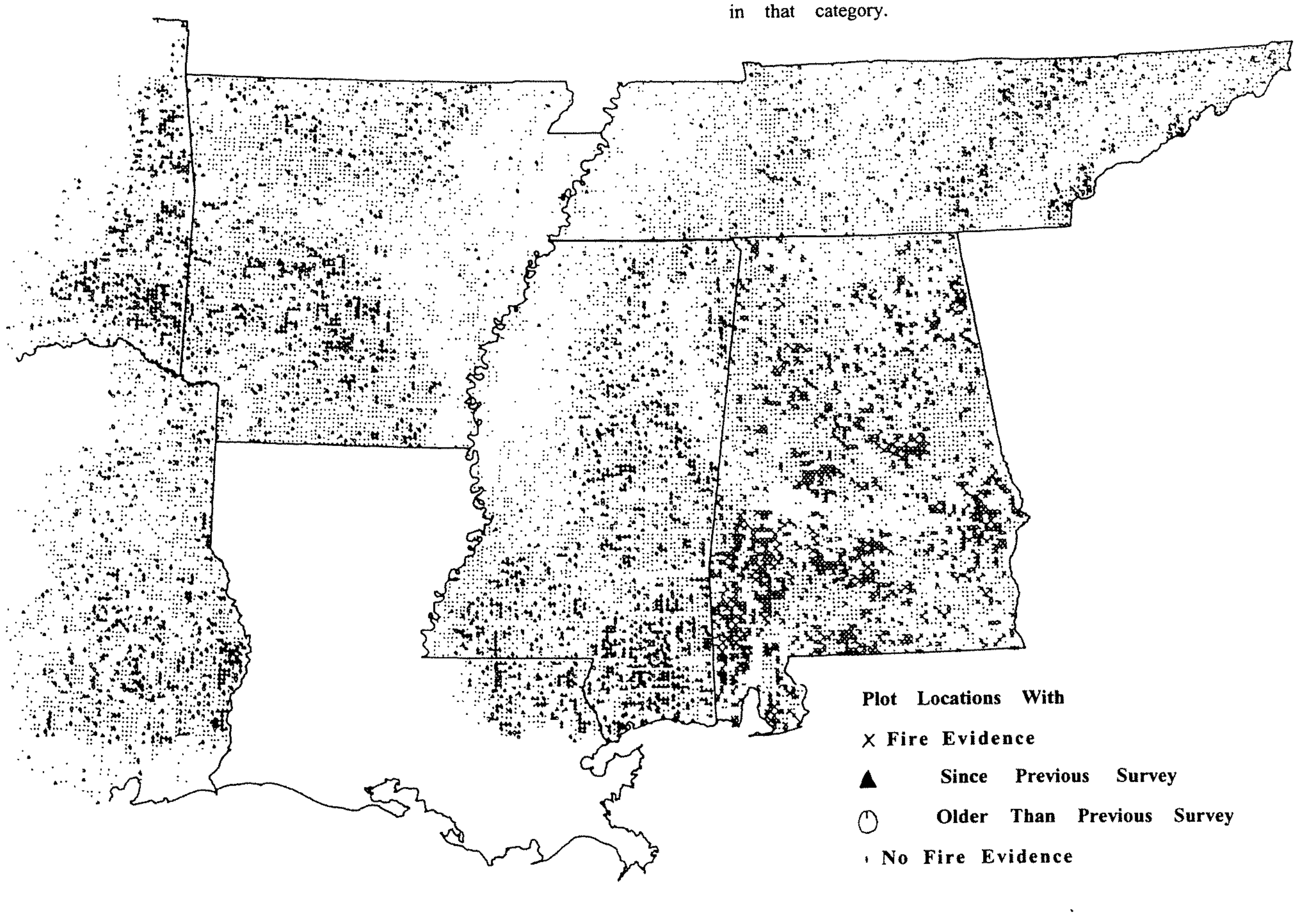

Figure 3.--Timberland area surveyed with and without fire evidence

Table 3.--Area with fire evidence by stand-size class, ownership class, and potential causal agent.[a]

Stand-size class and potential causal agent	All owners	Public land	Forest industry, incl. leased	Farmer	Other private
	Ownership class				
	. . . . Million acres				
ALL sizes					
Timber production	5.74	0.83	2.95	0.46	1.50
Timber and Livestock or wildlife production	1.67	.14	.97	.18	.37
Livestock or wildlife production	.68	.06	.13	.26	.22
Miscellaneous cutting or clearing	.30	.06	.08	.06	.09
Other	2.44	.41	.41	.42	1.20
Natural disturbances	.39	.05	.08	.09	.17
Total	11.22	1.56	4.63	1.47	3.56
Sapling-seedling[b]					
Timber production	2.98	.21	1.89	.21	.66
Timber and Livestock or wildlife production	.91	.06	.62	.08	.15
Livestock or wildlife production	.24	.01	.05	.09	.08
Miscellaneous cutting or clearing	.07	.02	.02	.02	.01
Other	.54	.06	.08	.12	.28
Natural disturbances	.19	...	.04	.05	.10
Total	4.93	.36	2.70	.57	1.30
Poletimber					
Timber production	.93	.09	.43	.10	.31
Timber and Livestock or wildlife production	.24	.01	.14	.02	.06
Livestock or wildlife production	.17	.01	.05	.07	.05
Miscellaneous cutting or clearing	.06	...	.03	.01	.02
Other	.74	.13	.16	.10	.34
Natural disturbance	.07	.02	.01	.01	.02
Total	2.20	.25	.83	.31	.80
Sawtimber					
Timber production	1.83	.54	.62	.15	.53
Timber and Livestock or wildlife production	.52	.07	.22	.08	.15
Livestock or wildlife production	.27	.04	.03	.11	.09
Miscellaneous cutting or clearing	.17	.05	.04	.03	.06
Other	1.16	.22	.17	.19	.58
Natural disturbance	.14	.03	.03	.03	.05
Total	4.09	.95	1.10	.59	1.46

[a] Excludes Alabama (7.1 million acres) and other surveyed states with fire evidence older than the prior survey (4.1 million acres).
[b] Includes 53,000 acres classified as nonstocked.

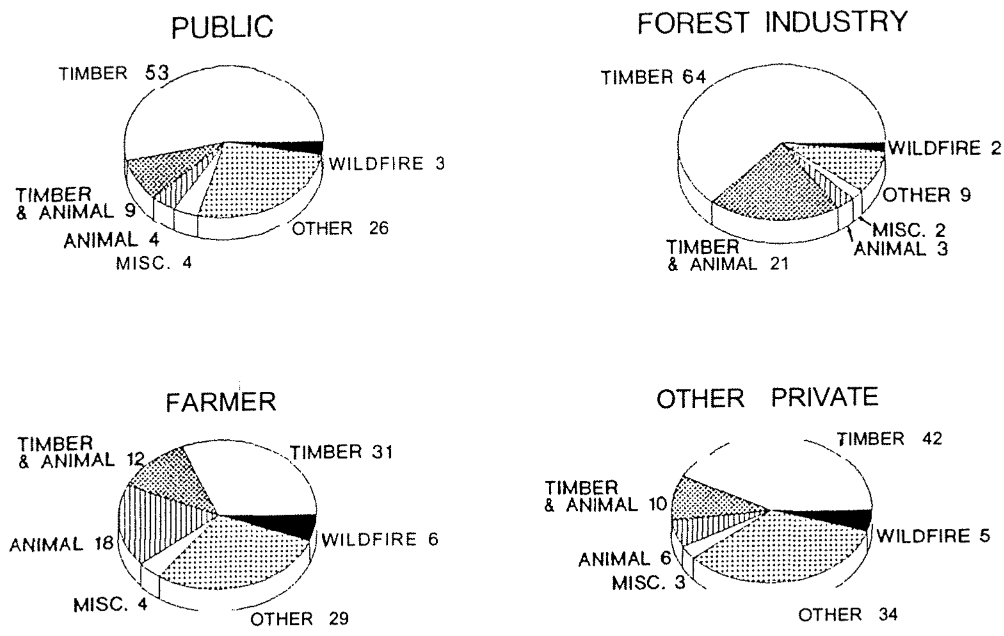

Figure 4.--Percent timberland area with fire evidence since the previous survey by ownership class and potential causal agent (excludes Alabama),

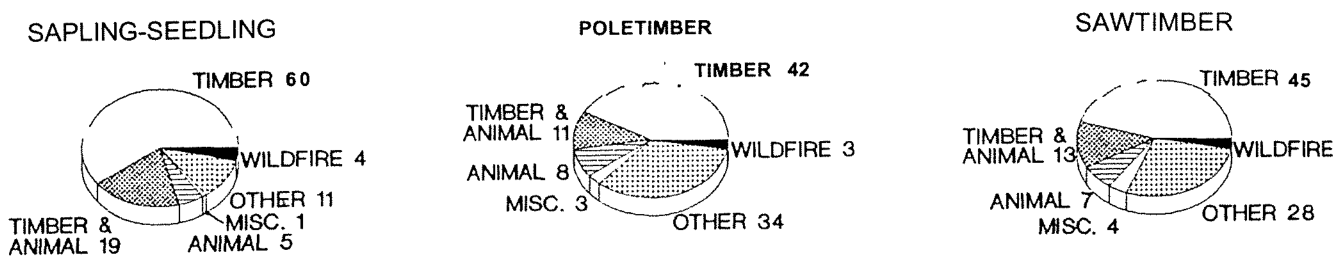

Figure 5.--Percent timberland area with fire evidence since the previous survey by stand-size class and potential causal agent (excludes Alabama).

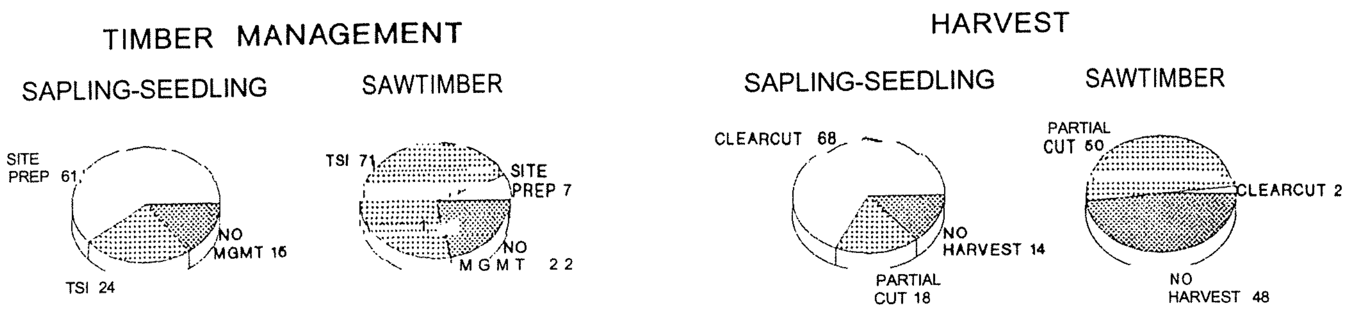

Figure 6.--Percent timberland area with fire evidence and timber production activity by type of timber management and harvest activity (excludes Alabama).

Figure 6 contrasts the occurrence of fire evidence in sapling-seedling stands and in sawtimber stands with timber production by management and harvest activities. Timber management includes site preparation (SITE PREP) and timber stand improvement (TSI); no management (NO MGMT) refers to harvest with no management. Timber harvest includes partial cut and clearcut; no harvest refers to timber management with no harvest activity. A majority of the fire evidence occurring with evidence of timber management is associated with site preparation in sapling-seedling stands and with timber stand improvement in sawtimber stands. In sapling-seedling stands, the majority of fire evidence associated with timber harvest is associated with clearcut operations. In sawtimber stands, most fire evidence associated with timber harvest is associated with partial cut operations.

Estimates of average annual fire occurrence by State, causal agent, and data sour-cc arc presented in table 4. It is worth noting that the causal agent estimates derived from forest survey data arc generally consistent with the estimates based on data from other sources. There is 95 percent confidence that forest survey total acres are reliable within the intervals noted.

DISCUSSION

Forest survey plots arc: categorized simply as having or not having fire evidence, and no interpretation is made regarding fire source. While this limits analysis of the data, the extensive and systematic sampling conducted during forest surveys yield descriptive regional information of heuristic importance. There also will be opportunities to assess trends in fire evidence when the area under study is resurveyed in the near future.

Total acreage with fire evidence from forest surveys represents an estimate of the cumulative acreage burned. No separate estimate is made for the acreage burned more than once between surveys. The forest survey estimate is based on a sample and has a corresponding error associated with the sampling process. In general, sampling error increases as the area considered decreases. Ninety-five percent confidence intervals arc generally within 5 percent of the acreage estimates for data aggregated over multi-county and larger areas.

Since most plots arc surveyed about every 10 years, we feel confident that observations of fire scars, vegetative growth since the last fire, management activities, and other disturbances can be observed readily. However, we feel that analysis of fire evidence by causal agent should be interpreted with caution. For example, fire is attributed to "other" agents less often for forest industry-owned land and in sapling-seedling stands than stands belonging to other categories (figs. 4 and 5). Survey results suggest at least two hypotheses: (1) fire evidence is associated with forest management activities in younger, sapling-seedling stands and on forest-industry land, rather than in older stands or on land in other ownerships; (2) fire evidence occurring in poletimber and sawtimber stands and associated with "other" agents is caused by low-intensity surface wildfires that do little damage tu trees, whereas fire evidence observed in sapling-seedling stands is associated with damage that is readily attributed to wildfire. An extension of the second hypothesis is that because forest industries employ prescribed fire to a greater degree than other landowners, fires caused by "other" agents may have less opportunity to occur.

Although we suggest that co-occurring evidence on sampled plots provides clues to the origin of fire evidence, we recognize the weakness of the assumption. Additional field measurements are needed to test this assumption to quantify fire impacts on forest ecosystems, and to estimate wildfire potential. Development of models that relate the type, intensity, and frequency of fires to fire evidence, e.g., litter depth on plots with and without fire evidence, and the addition of field measures to FIA plots that quantify potential surface moisture and the amount of live and dead materials would be useful in this regard.

Comparison With Other Estimates

We have already said that "ballpark" estimates of fire occurrence can be inaccurate. Nevertheless, the only available estimates of regional fire occurrence arc "ballpark" ones. Are forest survey estimates consistent with existing regional estimates of annual fire occurrence?

Except in the case of Alabama, FIA estimates of acreage arc from 13 to 43 percent higher than estimates from other sources. There are many reasons why estimates from other sources are lower. FIA estimates represent averages of cumulative acreage with fire evidence, include prescribed fire as well as wildfire, and represent estimates for public, forest industry, and nonindustrial private lands. Estimates from other sources often represent acreage burned in a single year or averages over a few years; such figures also include prescribed fire and wildfire estimates for different reporting periods and landowner groups. Information from other sources is not as likely to come from all forested areas, particularly in the case of prescribed fires not associated with timber production activities.

Table 4.--Average annual fire occurrence by state, causal agent, and source of data.

State and causal agent	Forest Survey[a] Years	Forest Survey[a] Percent	Forest Survey[a] Thousand acres	(+,- 2 S.E.)	Other sources[b] Thousand acres	Other sources[b] Percent	Other sources[b] Years
Alabama[c]	1973-82						
Prescribed fire		44	318.1	(15.4)	518.1	68	1975,84[d]
Other agents-wildfire		56	407.3	(17.5)	238.9	32	1988
Total			725.4	(23.3)	757.0		
Arkansas	1979-88						
Prescribed fire		77	191.2	(7.1)	182.6	84	1975,88[e]
Other agents-wildfire		23	58.2	(3.9)	34.9	16	1988
Total			249.4	(8.1)	217.5		
Southeast Louisiana	1975-84						
Prescribed fire		74	53.9	(5.4)	57.6	90	1975,84[f]
Other agents-wildfire		26	18.7	(3.2)	6.6	10	1988[g]
Total			72.6	(6.3)	64.2		
Mississippi	1978-87						
Prescribed fire		79	333.2	(14.0)	233.5	68	1975,84[h]
Other agents-wildfire		21	91.1	(7.3)	108.9	32	1988
Total			424.3	(15.8)	342.4		
East Oklahoma	1977-86						
Prescribed fire		60	80.5	(8.5)	55.0	59	1977-86[i]
Other agents-wildfire		40	53.7	(6.9)	39.0	41	1977-86[i]
Total			134.2	(11.0)	94.0		
Tennessee	1981-89						
Prescribed fire		51	46.5	(4.6)	26.9	35	1975,84[j]
Other agents-witdfire		49	45.1	(4.6)	51.0	65	1988
Total			91.6	(6.5)	77.9		
East Texas	1977-86						
Prescribed fire		83	160.3	(8.0)	123.8	79	1975,84[k]
Other agents-wildfire		17	33.7	(3.7)	52.9	21	1988
Total			194.0	(8.8)	176.7		

[a] Elapsed time in years: AL=9.8, AR=9.5, LA=9.1, MS=9.5, OK=9.8, TN=9.0, TX=10.4.

[b] 1988 wildfire estimates are from USDA-FS (1988b). For the entire South, average annual acres burned by wildfire has changed little in the past decade (USDA-FS 1988a). 1975 prescribed fire estimates are from Johansen and McNab (1982).

[c] May include fire evidence older than previous survey.

[d] Average of 157,320 acres (1975) and 878,970 acres (1984) (Moody 1985).

[e] For 1988: 35,200 acres National Forest (USDA-FS 1988a), and 15,000 acres by the State Forestry office (Garner Barnum, pers. comm.). For 1975: on private Land, 132,350 acres in 1975. More recent data on prescribed fire use on forest industry Land are not available (Garner Barnum, pers. comm.)

Statewide average of 462,420 acres (1975) and 450,000 acres (1984) (Miles 1985) adjusted for the portion of forested area surveyed.

[g] Statewide estimate adjusted for the forested area surveyed.

[h] Average of 167,050 acres (1975) and 300,000 acres (1984) (Miles 1985).

10-year average, 1977-1986, based on state and forest industry records (Kurt Atkinson, Oklahoma Forestry Division, pers. comm.).

Average of 31,700 acres (1975) and 22,100 acres (1984) (Ashley 1985).

[k] Average of 47,600 acres (1975) and 200,000 acres (1984) (Miles 1985).

IMPLICATIONS AND CONCLUSIONS

What can we conclude from the data presented? There are three major conclusions: (1) fire evidence is pervasive in the South Central States, (2) fire evidence is concentrated in pine--growing parts of the South Central States, (3) observations of evidence of fire occurrence from forest surveys can be used as a basis for credible estimates of past fire occurrence.

Projections of forest acres in South Central States by forest type suggest a continuing increase in pine plantation acreage and a corresponding decrease in natural pin e acreage, a trend that has continued since 1970 (Birdsey and McWilliams 1986). If evidence of past fire occurrence is an indication of future trends, a* increase in pine plantation acreage will be associated with increased fire frequency. Any existing or proposed policies for regulating fire to reduce smoke hazard or increase protection from wildfire will have widespread consequences for forestry in this region.

Forest survey fire evidence data can be used as a basis for studying the potential for air quality degradation and fire danger at the regional level. When combined with wildfire and weather statistics, forest survey fire evidence data can be used to establish regional forest protection priorities. The data presented can be used as a basis for assessing fire occurrence in studies of water, livestock forage, wildlife habitat, and timber production in multi-county and larger areas. That forest industries and other ownership groups in selected regions have considerable acreage with tire evidence suggests that fire plays an important role in these areas. The regional extent of this influence is documented in this report and should be considered when discussing forest management policy and the future condition of forest ecosystems in the South Central States.

The extent and importance of fire's effects on South Central States' forests cannont be fully elucidated from forest survey data without additional information. Because there exists a wide array of forest characteristics, including previous land use and ownership data, testing inferences regarding prescribed fire and wildfire origins on a subsample of plots should prove fruitful. Linkage of forest survey fire evidence data with a suitable geographic information system also can provide regional modelers with supplementary data for use in assessing other values (e.g., water quality and soil erosion) affected by fires.

Continued monitoring of fire evidence on forest survey plots can supply analysts with information about trends in past fire occurrence. Additional measures needed to identify causal agents could he developed for a carefully selected subsample of plots and then modeled for all plots. Such a method would be especially useful for monitoring trends in fire use as a management tool and evaluating fire's effectiveness in increasing timber productivity and other multiple-value forest resources,

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A SITE-SPECIFIC APPROACH FOR ASSESSING THE FIRE RISK TO STRUCTURES AT THE WILDLAND/URBAN INTERFACE

Jack D. Cohen'

Abstract-The essence of the wildlandiurban interface fire problem is the loss of homes. The problem is not new, hut is becoming increasingly important as more homes with inadequate adherence to safety codes are built at the wildlandiurban interface. Current regulatory codes are inflexible. Specifications for building and site characteristics cannot be adjusted to accommodate homeowner values. USDA Forest Service Fire Research is developing a wildlandiurban fire interface ignition assessment model as an alternative to current tire safety codes. This model is based on an analytical (rather than statistical) assessment of structural characteristics, site characteristics, and fire severity conditions. The model will be capable of assessing ignition risk for individual structures, and thus will be capable of accommodating homeowner preferences as they affect fire safety.

INTRODUCTION

More than 1,400 homes were damaged or destroyed during wildland fires in Florida, North Carolina, California, and other States during 1985 (Laughlin and Page 1987). This created national interest in what has come to be called the wildland/urban interface fire problem. Interest in the problem continues to grow as the number of people who live in or adjacent to wildland areas increases (Davis 1990).

Although new emphasis has been placed on the problem of structure loss and damage associated with wildland fires, the problem is an old new. During the last 30 years, frequent conflagrations in California have resulted in losses of structures, primarily homes. After major California fires, reports that identified the fire problem and provided guidance for mitigation were generated (California Department of Conservation 1971; California Department of Forestry 1980; County Supervisors Association of California 1965; Howard and others 1973; Moore 1981; Radtke 1983). Generally, these reports were commissioned by State and local government agencies. With some exceptions (Dell [n.d.]; Radtke 1982), the target audiences were public officials and fire professionals. Many of these wildlandiurban fire reports were comprehensive, providing recommendations, including technical specifications, for urban planning, fire suppression capabilities, vegetation management, and building construction. However, despite the production of these reports, the wildlandiurban interface fire problem has continued with little abatement.

Little attention has been given to the social aspects of the wildlandiurban interface fire problem, and this may be one reason why the problem persists. The technical aspects of this fire problem such as building codes and suppression improvements, have dominated discussions about the subject. However, the social aspects of the wildland/urban fire problem gained attention at wildlandiurban interface workshops conducted during 1986 and 1987 (Laughlin and Page 1987; USDA Forest Service 1987). The participants concluded that a solution to the fire problem must recognize and accommodate homeowner values and motivations.

The social aspects of the problem have not yet been addressed in the practical arena. Current fire standards are generally embodied in zoning and building codes (specification codes). These specification codes regulate minimum allowable building and site characteristics. Examples of specification codes include requirements for street width, the number of structures per area, vegetation clearance, roof material, and screening of vent openings. Standards such as these (California Department of Forestry 1980; County Supervisors Association of California 1965; Moore 1981) recommend minimum building and site characteristics for improving structure survival. Where these recommendations are implemented, structure survival is increased -- but they are generally not implemented at the wildland/urban interface.

Specification codes cannot make allowances for the diversity of social values. Generally, specification codes are not flexible in responding to homeowner values and motivations; trade-offs cannot be made to achieve a fire-safe condition. Specification codes are implemented or they are not. As a result, specification codes connote uncompromising compliance with government imposed regulations. Because many of the property owners who live in wildland/urban interface areas move there to escape urban regulation (Bradshaw 1988), there is great resistance to fire safety regulations that restrict building and site characteristics. This suggests the need for a regulatory approach that can make allowances for the diversity of social values while it identifies measures for reducing the fire risk.

This article examines the wildlandiurban interface fire problem in terms of structure ignition and survival. It also describes a current USDA Forest Service effort to develop a flexible method for assessing the relative risk of structure ignition.

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THE WILDLAND/URBAN INTERFACE FIRE PROBLEM--STRUCTURE SURVIVAL

The essence of the wildland/urban interface fire problem is the damage to homes during wildland fires. Any attempt to analyze the problem should recognize the various factors that influence the survivability of homes during wildland fires.

Structure survivability is the probability that a building will not suffer major structural damage during a fire. A structure's survivability depends on the structure's resistance to ignition and on the ability to suppress any ignitions that might occur. Thus, theoretically, for a given likelihood of structure survival, a variety of ignition resistance levels can be balanced by compensating suppression capabilities. This introduces the idea of trade-offs--in this case, ignition resistance for suppression capabilities, and vice versa.

Structure survival can be examined in greater detail. The ignition aspect of structure survival can be further defined in terms of the structural fire performance, the fire exposure, and the fire severity conditions. Similarly, the suppression aspect can be defined in terms of suppression availability, safe access to the structure, and fire severity conditions. It is helpful to consider each of these factors in greater detail.

fire performance: During a wildland/urban interface fire, ignition sources, i.e., firebrands, impinging flames, convective heating, and radiative heating, are initially external to the structure. Structural fire performance is the susceptibility to ignition and the degree of subsequent fire involvement. Structural fire performance depends on the physical characteristics of the structure. For example, a concrete structure with no window openings would resist an external ignition more than a structure with large window openings and an exterior covered with wooden shingles. Also, if an ignition occurs, the rate of fire involvement would very likely be greater for the wooden structure. The concrete structure has a higher fire performance than does the wooden structure. These simple examples represent the extremes of a broad spectrum of physical characteristics that determine structural fire performance.

Fire exposure: The fire exposure of a structure is defined here as the external sources (burning materials excluding flaming brands) of radiative and convective heating, and the site characteristics that influence the amount of heat transferred to the structure. For example, burning trees, shrubs, and wood piles at various distances from the structure determine how much the exterior is heated. When there is burning material downslope from the structure, the potential for convective heating is increased. In terms of fire exposure, only those burning materials close enough to the structure to influence an ignition are considered as heat sources. The area containing such materials can be termed the fire exposure zone. In this way, the concept of fire exposure can be used to distinguish wildland vegetative fuels (outside the fire exposure zone) from vegetation adjacent to a structure. Because a fire exposure zone is defined by the characteristics of the fire and the fire performance of the structure, fire exposure is not limited by property lines. Thus, the delineation of a site-specific fire exposure zone aids in identifying all of the flammable materials relevant to structure survivability.

Fire suppression availability: Availability of protection during a fire is an important aspect of structure survival. Structure ignitions, if extinguished, can occur without the loss of the structure. The quantity of fire suppression staff and equipment, together with training, experience, and response times, determines fire suppression availability. This factor is generally considered the domain of fire suppression organizations, but community residents are also a part of the fire suppression availability factor. Residents are often the source of fire reports and augment organized suppression forces by working to protect individual properties.

Access: Accessibility is critical for the utilization of available suppression resources, and thus to structure protection during a fire. Access is the ability of fire suppression forces, including residents, to locate, reach, and safely remain at a structure and continue suppression efforts.

Fire severity conditions: This refers to the conditions that affect the flammability of fuels, flame tilt, spread rates, and aerially transported burning brands. Fire severity conditions are determined primarily by on-site weather and topography. Fire severity conditions influence the degree of fire exposure and the effectiveness of structure protection.

Structure survivability is an expression of the interactions of the above-defined factors. Specification codes seldom take these factor interactions into account, and therefore present relatively rigid formulas for providing fire-safe environments. The failure to account for these factor interactions prevents the incorporation of social values into fire safety measures. The alternative to specifying minimum characteristics (specification codes) to produce a given level of structure survival is to make use of a model that incorporates factor interactions.

The essence of structure survival, and thus of the wildland/urban fire interface problem, is ignition. If ignitions do not occur, then structures survive. Although structure survival involves the interaction of all five factors discussed, just three of them--structural fire performance, fire exposure, and fire severity conditions--determine the potential for ignition. For a given level of fire severity, the ignition potential determines the level of fire suppression availability and accessibility necessary to produce a given level of structure survival. As structural fire performance decreases and fire exposure increases (increasing the ignition potential), the accessibility and suppression availability must increase if a structure is to survive. The wildland/urban fire interface problem would virtually disappear if structures did not ignite; therefore, the emphasis of a wildland/urban interface fire risk assessment should be on structure ignition.

IGNITION RISK ASSESSMENT MODEL

A structure ignition risk assessment model is now being developed by the USDA Forest Service. This cooperative effort involves the Forest Products Laboratory, Madison, WI, the Riverside Fire Laboratory, Riverside, CA, and the Southern Forest Fire Laboratory, Macon, GA. The product will be a broadly applicable method for assessing the relative risk of individual homes to external ignitions from wildland fires. The prototype model is expected to be completed in 1991.

This model approaches interface home losses in a new way. Recent models by Abt and others (1987) in the United States and Wilson (1988) in Australia have used statistically derived relationships, based on specific fires, to describe characteristics related to potential fire incidence and structure survival. Our model uses analytical relationships to describe characteristics related to the potential for structure ignitions. This approach has the following advantages:

- An analytical approach is not limited by specific event data and its interpretation,
- An analytical approach, based on physical relationships can easily incorporate future gains in understanding to fill current gaps,
- An analytical approach can incorporate the interactions of the various factors affecting the wildland/urban interface fire problem,
- The modeling of interactions provides a means for analyzing mixes of factors, and thus a means for analyzing trade-offs in meeting fire safety requirements.

Our wildland/urban fire interface model assesses the risk of potential ignitions rather than potential structure survival. As noted previously, structure survival depends on both the ignition factors and the suppression factors. Thus, an assessment of potential structure survival would require an assessment of the suppression factors. However, many of these factors (access, suppression availability, and tire severity) are very hard to quantify. For example, the resident's presence at the home during the fire can be critical to the home's survival. But it may not be possible to reliably assess the likelihood that a homeowner will be at home at an unspecified time, especially in a situation complicated by emergency access limitations and evacuation policies. (The statistical models previously cited also do not account for the suppression factors, although structure survival is ostensibly the product of the Australian method.)

The Ignition Risk Rating System

The Ignition Risk Rating System borrows some of its underlying philosophy from the National Fire Danger Rating System (NFDRS) (Deeming and others 1978) The Risk Rating System is based on physical principles so that new understanding can be easily incorporated into it. Where gaps in knowledge exist, personal expertise estimates the effects of the physical processes. As with the NFDRS, the ratings are not incident-specific, but rate the potential fire situation. Therefore, a worst case approach is taken in acquiring data and making computations. Because it is not possible to make precise evaluations of ignition occurrences, the risk ratings are placed in ordinal categories.

Rating risks of potential structure ignitions requires that structure characteristics, site characteristics, and fire severity conditions be described and analyzed to produce assessments. The Ignition Risk Rating System does this in three stages. In their computational order, these stages are the fire source module, the heat transfer module, and the structure ignition module.

The fire source module describes the site and fuels around the structure and transforms that information into descriptions of the potential flaming sources affecting the structure. The fire severity conditions are locally identified using National Fire Danger Rating System (NFDRS) burning index cumulative frequency percentiles. The percentiles are computed from historical fire weather data. The flaming source descriptions are based on an on-site fuel inventory in conjunction with the potential fire behavior identified by the NFDRS calculations. The potential flaming sources are described by their flame length, flame zone depth, flaming width, flaming duration, and distance from the structure. A subjective assessment of the structure's relative firebrand exposure is made on the basis of the fuel sources adjacent to the structure and on nearby wildlands. For example, a structure is considered less exposed to ignition by firebrands from grass fuels than by a conifer stand with heavy understory fuels. These descriptions are then used by the other modules.

The heat transfer module uses flame source and homesite information from the flame source module to estimate the radiative and convective heating of the building exterior. Due to the impossibility of knowing the specific characteristics of a future incident, the worst case configurations for the heat transfer are used. For example, all fuels are considered to be burning at the same time, the radiative distance is considered to be the closest distance to the fuel, and the view angle between the structure and the flames is assumed to be the angle that produces the greatest heat transfer. Convective heating occurs if the convection column intercepts the structure, but potential cooling from the wind is not considered.

The structure ignition module calculates the System's ignition risk rating. The module uses descriptions of the building's exterior structural characteristics along with the heat transfer information and the assessed firebrand exposure to compute the ignition risk. Exterior materials are generally described by type (wood, stucco, glass, etc.) and exposed surface area. The ignition risk assessment is largely based on data derived from laboratory fire tests conducted on exterior building materials (roof materials, siding, windows, etc.). The module produces the ignition risk rating based on the relative availability of energy for an ignition. Relative risk ratings fall into four classes: low, moderate, high, and extreme. To facilitate a consistent assessment of the ignition potential, the classes are defined in such a way that a structure in the next higher class has twice as much ignition potential as a structure in the one below.

System Benefits

The System will provide property owners and suppression organizations with a guide to assessing, and thereby reducing if necessary, the potential ignition risks to homes. The System will provide the following:

- A flexible means of integrating social values and tire performance requirements--one that will encourage greater acceptance of actions necessary to decrease the risk of structure ignition,
- A means for evaluating a mix of conditions of the components that contribute to structure ignition, thus allowing for site-specific and property-owner-specific actions that meet minimum requirements for ignition risk--making informed tradeoffs,
- A means for informing and educating property-owners about the relative risk to their homes,
- A means for informing suppression agencies of the relative fire risk to homes, leading to more informed suppression planning.

SUMMARY

The wildland/urban interface fire problem, i.e., the loss of homes during wildland fires, is not new. The problem persists, not because there are no fire safety guidelines, but because guidelines are not fully implemented. Until recently, homeowner values and motives were not recognized as important in achieving fire safe home sites. The current guidelines used for the wildland/urban fire interface are fixed, discrete specifications that cannot incorporate variations in homeowner values while maintaining a given level of fire safety.

A USDA Forest Service cooperative research effort is currently developing a wildland/urban interface structure ignition risk assessment model. This physically based analytical model is being designed to account for the interactions of the factors that contribute to structure ignitions. Thus, the model may be used to identify a variety of fire safety measures that result in required risk reductions and also accommodate specific homeowner desires.

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PERCEPTION OF FIRE DANGER AND WILDLAND/URBAN POLICIES AFTER WILDFIRE

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Abstract-Quantitative analysis conducted after the May 1985 Palm Coast fire in Florida identified several residential characteristics that influenced vulnerability to wildfire. As a followup to that analysis, homeowners were surveyed to determine their perception of fire danger and to determine their views on alternative mitigation measures they have undertaken as individuals and their view of alternative government mitigation policies. The survey indicates that homeowners perceive wildfire as a serious threat to their safety and property. Homeowners were receptive to a wide variety of government policy options, including restrictive planning, zoning, and building requirements. Older homeowners were more likely to have taken mitigation measures and were more receptive to government intervention.

INTRODUCTION

Palm Coast is a 42,000.acre planned unit development situated in the coastal plain flatwoods along the east coast of Florida. Prior to its development, the land was actively managed for pine timber production. Timher management included the periodic use of prescribed fires to control fuel buildup.

Typical of other large developments that started in Florida in the 1960's, Palm Coast was primarily a lot-sales venture. Individuals purchased land using a long-term payment plan with the intention of building at some future date. All roads, underground utilities, and drainage systems were installed within the first 10 years of construction. Except for a densely developed core, homes have been built sporadically throughout the development. Prescribed fires were no longer used after construction began.

In May 1985, a devastating wildfire burned through Palm Coast, destroying 100 homes and damaging 200 others. Lack of brush clearance, fire intensity (due to abundant fuels), type of soffit vent, and type of construction were shown to have been associated with increased fire losses (Abt and others 1987).

In 1988, the Federal Emergency Management Agency and the United States Forest Service jointly funded a followup study to determine homeowner perception of the wildfire threat and attitudes toward various mitigation strategies. Additional objectives were to determine how mitigation could be incorporated into the land-use planning process and to determine the vulnerability of recently built homes. The purpose of this paper is to summarize the residents' perception of wildfire danger, the mitigation measures taken, and attitudes toward various mitigation policies.

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METHODOLOGY

The study was conducted jointly by the Florida Division of Forestry (DOF) and the University of Florida. A mail survey was designed to gather information about the residents and their perceptions about wildfire. The survey included a cover letter signed by the local district forester and fire chief. Two survey areas were selected. One was an area burned in the 1985 fire and the other was a nearby area of similar housing density that was not damaged by the fire. All of the homes in the two sections were surveyed. The survey was hand-delivered by DOF personnel and returned via business reply mail. Three weeks after the surveys were distributed a follow-up letter was mailed. Approximately 276 questionnaires were distributed. There were 124 usable questionnaires returned for a 45-percent response rate. A followup survey of 40 nonrespondents (20 in each section) revealed that many of the houses were vacant. The few followup surveys completed by nonrespondents did not reveal any significant differences with respondents.

The survey questions reported here fit into four categories, (1) demographic information, (2) perceived threat of wildfire, (3) mitigation measures taken, and (4) attitude toward mitigation options. Simple summary statistics are reported below. Chi-square statistics were used to test for association between the demographic variables and resident acceptance of mitigation measures. For many of the subjective opinion questions a l-to-6 scale was used. The lower (1-to-3) end of the scale was used to represent lack of a threat or agreement with the question (3.5 represents neutral).

RESULTS

Initial tests for differences between the two sections of the development revealed that they differed only in the number of respondents who had personally experienced wildfire. The results reported here are the combined responses from both sections.

Demographics

The section of Palm Coast surveyed is predominantly a retirement community. Sixty percent of the homes have one or more family members over 65. Only 25 percent of the homes have children under the age of 18. The average age of the respondents was 56. On average the respondent had lived in the current home for 3.6 years, and 75 percent planned to continue living in the community for at least 5 years. Most respondents (55 percent) had no more than a high school education, though 25 percent had at least a bachelor's degree. The median income was approximately $30,000, and the average market value of the homes was $98,000. Though these statistics give an overview of the community, their primary value was as an explanatory variable in determining attitudes toward mitigation. These analyses are described below.

Perceived Threat of Wildfire

Two aspects of wildfire threat were surveyed. The first was the perceived danger of a wildfire to the home and family if it were to occur. The second was the perceived probability of a wildfire occurring. The questions regarding the perceived threat from wildfire were put into the context of other threats facing the community.

The first table below shows how the respondents viewed wildfire compared to a wide spectrum of common problems. Wildfire was considered the most serious threat facing the community, even 4 years after the major fire. This is especially important given that 69 percent of the respondents had been in their current home for less than 4 years (after the wildfire). The perceived threat of wildfire to the home and family was measured on a 1 to 6 (1 =no threat, 6=extreme threat) scale. The perceived threat of hurricanes and tornadoes was also collected. Wildfire was given an average score of 4.8 as a threat to the home and a score of 4.5 as a threat to the family. Wildfire was rated higher in both categories than either hurricanes or tornadoes.

Perceived problems facing the Palm Coast community:

	Mean score
Economic problems (unemployment, inflation, etc.)	2.98
Drought	3.99
Crime rates	3.59
Illegal drugs	4.04
Damage or injury from hurricanes	2.49
Damage or injury from tornadoes	2.34
Damage or injury from wildfire	5.09
Exposure to radon	2.18
Water supply	3.07

[2]1 = no problem, 6 = most serious problem.

The above questions asked about the threat of a wildfire if it were to occur. There are at least two other factors that will determine whether a resident should take action to mitigate the damage. The first is the perceived probability of wildfire occurrence and the second is the perceived effectiveness of mitigation.

Residents were asked to give their best estimate of the chances of a serious wildfire in their community in the next 10 years. The average estimate was 57 percent, which was higher than either tornado or hurricane. Residents were also asked to rate on a 1 to 6 scale the control they had over wildfire damage (1 =no control, 6=complete control). The average response was 3.0 which was higher than either tornados or hurricanes. Given the high probability and threat associated with wildfire and the high percentage of new homes, one might expect that vulnerability to wildfire would be important in the choice of a home. When rated on a 1 to 6 scale (1 =not important, 6=extremely important), however, vulnerability to wildfire only rated 2.5 in choice of current home.

The perceived threat of wildfire to the home was associated with education (.04 significance level), where residents with education beyond an undergraduate degree felt less threatened. Residents whose insurance would cover all or most of the damage from a wildfire also felt less of a threat (.08 significance level). The perceived threat of wildfire to the community was related to age, personal wildfire experience, and income. Residents over 65 and residents who had experienced wildfire were far more likely to rate wildfire an extreme threat (.03 and < .01 significance levels respectively). Middle income ($40K-$50K) residents rated wildfire as less of a community threat than others (.02 significance level). New residents (< 4 years) were far more likely to have considered wildfire vulnerability in their home choice. Those who had experienced wildfire, however, felt they had less control over wildfire damage.

Mitigation Measures Taken

Sixty-seven percent of the respondents reported that they had taken some sort of precaution against wildfire. The probability of having taken safety measure was positively related to whether the resident or a close friend had experienced wildfire (.03 and .01 significane levels respectively). The older residents (> 45) were more likely to have taken measures (.002 significance level). Residents without children at home, which were probably the older residents, were also more likely to have taken precautions (.03 significance level) as were homeowners (versus renters) and residents who planned to stay in the community for at least five years (.003 and .04 significance levels).

Ninety-three percent of these safety measures were taken after the 1985 wildfire. Most measures taken cost less than $100 (65 percent). The most common measure was tree or brush removal (53 percent). Others removed mulch (14 percent) or purchased fire safety equipment (25 percent, including water hoses, pool pumps, sprinklers, extinguishers, etc.).

Attitudes Toward Mitigation Policies

Resident attitudes about various mitigation measures and government policies were examined. A wide variety of measures were examined from passive voluntary measures to restrictive governmental intervention. As the tabulations below show, the residents generally favored any and all mitigation measures mentioned. Even controversial measures such as mandatory brush clearance and community-wide control burning were considered acceptable.

Attitude toward government mitigation policies:

Government agencies should:	Mean score'
Provide financial assistance to victims	2.3
Prohibit building in hazardous areas .	2.2
Impose stricter building codes in hazardous areas	1.8
Provide information to homeowners in hazardous areas	1.5
Conduct research on ways to reduce damages	1.8
impose stricter zoning requirements in hazardous areas	1.9
Impose stricter planning requirements in hazardous areas	1.8
Provide non-financial assistance to victims . . .	2.7

'1 = no problem, 6 = most serious problem

Attitude toward mitigation measures:

	Mean Score'
Voluntary brush clearance	2.0
Mandatory brush clearance	2.3
Mandatory home site survey for fire hazard	2.4
Community-wide control burning	1.9
Stricter building codes	2.0
Stricter planning requirements for developers	1.8
Increased wildland firefighting resources	1.7
Increased structural firefighting resources	1.9

[1]1 = no problem, 6 = most serious problem

Though there was general acceptance of government policies, older and permanent residents tended to accept restrictive policies, while highly educated residents tended to be less open to government intervention. For example, residents who planned to stay in the community for the next 5 years were three times more likely to favor government prohibition of building in hazardous areas (.005 significance level). Older residents (> 45) were four times more likely to favor strict planning (.034 significance level), Residents with education beyond an undergraduate degree were far more likely to oppose the imposition of codes, zoning, or planning restrictions (.00, .04, and .OO significance levels respectively). Lower income families (< $30K) were more likely to oppose nonfinancial support (.03 significance level) while those who had experienced wildfire were much more likely to favor non-financial support (.05 significance level).

There were only two resident characteristics that were significantly related to specific mitigation measures. Residents who planned to live in the community for at least 5 more years found a mandatory home survey more acceptable (.04 significance level), while homeowners were much more open to stricter codes than were renters (.04 significance level).

SUMMARY

Five years after the Palm Coast fire, residents consider wildfire the major threat to their community. Many residents have taken precautionary measures, though wildfire vulnerability was not important in home choice. Residents over 65 were more likely to consider wildfire an extreme threat and were more likely to have implemented mitigation measures. They were also supportive of all policies considered. Residents with an education beyond a bachelors degree, however, were less tolerant of possible government intervention.

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